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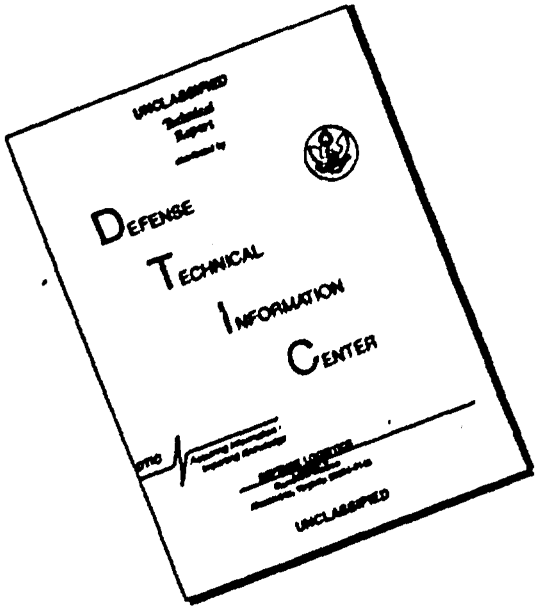

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TECHNICAL REPORT 2434

SURVEY OF DEVELOPMENT WORK ON PLASTIC ROTATING BANDS (U)

HENRY A. TISCH

AUGUST 1957

FC

SAMUEL FELTMAN AMMUNITION LABORATORIES
PICATINNY ARSENAL
DOVER, N. J.

ORDNANCE PROJECT TA1-5005

DEPT. OF THE ARMY PROJECT 3A04-03-051

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by

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Technical Report 2434

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Dept of the Army Project 5A04-03-061

Approved: J. D. Matlock

for L.H. ERIKSEN
Chief, Explosives and Plastics Laboratory

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OBJECT

To survey the development work performed in England and America on plastic rotating bands and, against that background, to report in detail on work performed in recent years at Picatinny Arsenal.

SUMMARY

This report contains:

a. A brief account of work on plastic rotating bands during the last 10 years at British ordnance facilities, at the Franklin Institute in Philadelphia, at the Naval Ordnance Laboratory and the Naval Proving Ground, and at Picatinny Arsenal (SFAL). This material is liberally cross-referenced to the Bibliography which constitutes a later section of this report.

b. A detailed discussion of several material investigations performed at SFAL. Properties of some of the most promising plastic materials for rotating bands are listed and discussed. Fabrication methods are dealt with and the results of local firing tests on the 57 mm scale are reported.

c. In a final section, plastic rotating bands under development at SFAL for several specific end items are discussed.

An improved method for measuring the spin of a projectile in free flight is described in the Appendix.

CONCLUSIONS

A considerable number of plastics have given good performance as rotating bands, when fired at low velocities.

Only a few plastics have shown promise at velocities of over 4,000 fps. The choice of materials will be narrowed even more if retention of bands in flight is made one of the performance criteria.

Development of special band designs will be needed before optimum performance can be obtained from plastic materials.

Firing of metal-banded and plastic-banded projectiles alternately from the same barrel cuts down the performance of plastic rotating bands and should be avoided.

Creation of special propellant gun-projectile systems for projectiles having plastic rotating bands should lead to higher velocities, lengthened gun life, and reduced costs.

INTRODUCTION

1. A prerequisite for good external ballistics is stable flight of the projectile. The majority of artillery projectiles attain stable flight by spin,

imparted by means of a rifled gun barrel and a rotating band. The rotating band, which is firmly fastened to the projectile, engages the spiral rifling of the gun barrel and thereby transmits stabilizing spin to the projectile. Obturation and centering of the projectile are, of course, almost equally important functions of a rotating band. A long list of additional functions and of necessary and desirable requirements could without difficulty be set up (Pages 12 and 13 of Item 46 of the Bibliography).

2. Copper and copper alloys have been used for rotating bands since the introduction of breech loading guns at about the middle of the 19th century. During the last 20 years, gilding metal (an alloy consisting of 90% copper and 10% zinc) has been used almost exclusively by the United States Army for bands on standard artillery ammunition. Because of their relatively high strength and high ductility, properly-designed gilding metal bands have given satisfactory performance in conventional weapons. Why then look for other materials?

3. There are two major and many minor reasons why we have to look not merely for substitutes, but for better performing materials for rotating bands. High speed warfare demands ammunition in quantities and at a level of quality that was previously unheard of. Under a war economy, serious shortages of copper and other non-ferrous metals exist. With the increased firepower of modern weapons, the development of strong non-strategic band materials and cheaper banding methods becomes imperative. This probably is the most pressing reason why we should have other materials to take the place of copper alloys for rotating bands. Another hardly less important reason is the fact that gilding metal bands of present design do not function properly at the hyper-velocities demanded of certain types of AA and AP ammunition. The difficulties encountered with present metallic banding materials are caused chiefly by excessive friction, frictional heat, and the high thermal conductivity of the metals used. A survey of readily available materials without the above-mentioned shortcomings indicates that a number of plastics may be classed as potential band materials.

4. During the past 10 years, development work on plastic rotating bands has been performed by a number of Ordnance facilities of the United States Army and Navy and also by the British Ministry of Supply. Investigations have been described and test results presented in over 60 reports (See Bibliography).

5. Lacking funds and priority, progress in the development of plastic rotating bands has been slow. Yet, in spite of these handicaps, definite progress has been made. Today several plastic materials are known to give credible performance and indications are that, by design improvements involving not only the band, but the whole propellant-projectile-gun system, high velocity ammunition

with plastic rotating bands can be developed and produced economically.

DEVELOPMENT WORK DURING LAST DECADE

In England

6. The first experiments with plastic bands, as far as can be determined from available literature, were performed at Ft. Halstead in England approximately 10 years ago. Whereas the United States was interested in plastic chiefly as a means of saving copper, emphasis in England was from the beginning placed on gun performance and reduction of wear. The English investigators reasoned that differences in properties between metals and plastics would prevent direct substitution of the one for the other. As a consequence, new designs of both bands and projectiles were investigated, and even modifications in the geometry of the chamber and forcing region of the gun. Also noteworthy is their almost exclusive use of the case-over-band design, to minimize dimensional changes in and damage to the plastic bands.

7. Certain attributes, such as heat resistance, hardness, and dimensional stability, apparently motivated the English investigators to concentrate at first on thermosetting plastics. Materials tried out in the early stages of development included: Ebonite (hard rubber made of natural rubber, neoprene, or GRS), phenolics, rubber-modified phenolics, cord-reinforced phenolics, and vulcanized fiber (See Items 1, 2, 3, 4, 7, 12, 13, 19, and 20 in the Bibliography).

8. In contrast to the American approach, the first trials in England were performed on medium-caliber guns. The 6 pdr (57 mm) and the 17 pdr (3 inch) guns were used for the first test firings of projectiles with plastic rotating bands ("driving bands" in the English terminology). Good spin and obturation were obtained in most cases. All bands discarded near the muzzle. This latter behavior was not at that time considered a shortcoming. On the contrary, it was concluded, that, if the bands came off 100%, this would improve exterior ballistics by decreasing the dispersion, decreasing the retardation, and increasing the range.

9. This reasoning apparently did not carry enough weight to be accepted, and it appears that another school of thought which believes that the rotating bands should stay on 100% has been adopted. Apparently, all attempts to retain in flight rotating bands made of the thermosetting plastics investigated up to this time were unsuccessful. A suitable tough material was sought and, after studying the known properties of all plastics, the British chose Nylon 6.6, a thermoplastic, as the material most likely to meet all requirements (See Items 22, 26, 27, 30, and 31 in the Bibliography). Years of thorough investigation of nylon bands followed. Performance after storage under adverse climatic conditions and in new and worn guns was determined.

Reports of test results range in tone from enthusiastic to pessimistic.

10. So far, nylon rotating bands have been standardized in England only for discarding sabot rounds such as the 20-lb (83 mm) Mark 3 APDS and the 120 mm projectiles. The 83 mm round is fired at velocities of 4000 fps or better. At this velocity, copper bands performed poorly.

11. Several shortcomings have thus far prevented adoption of nylon bands for other standard rounds. These shortcomings, as mentioned in British reports, are:

a. Erratic brittleness

b. Voids (small gas or vacuum bubbles) in molded bands

c. Embrittlement subsequent to molding, caused allegedly by progressive crystallinity, especially under conditions of high humidity and temperature and by degradation.

12. To overcome the difficulties encountered with Nylon 6.6, other polyamides, such as Nylon 6, Nylon 610, Nylon 11, and Nylon 66/610/6, were imported from the Netherlands, France, Switzerland and the United States. All are currently under investigation as banding materials in experimental work being performed with 40 mm ammunition (Items 32 and 33 of Bibliography).

13. Polyvinylchloride and Fromopias (a modified polyvinyl formal) have also been studied. Promising results were obtained, but there seem to be some drawbacks arising from the relatively low heat distortion point of these two plastics (Items 23, 32 and 33 of Bibliography).

14. One other material included in the earliest trials was vulcanized fiber. Bands made from this material performed very well in firing. Engraving on such bands was excellent. The only shortcoming appeared to be moisture sensitivity. After extensive trials, British engineers found that they could minimize this water absorption by using the bands only for rounds in which the band is covered by the case (that is, rounds of the case-over-band design).

15. In this early experimental work with 40 mm rounds, the fiber bands were held in place by undercuts at both edges of the band seat, and they stayed on reliably. In recent firing trials, the accuracy obtained by 40 mm and 83 mm rounds with vulcanized fiber bands was superior to that obtained by rounds with nylon bands (Items 14, 15, 16, 17, 18, 31, 32, and 33 in the Bibliography).

16. No data on barrel wear is available in the English reports. The following statements are taken from information given verbally to a representation of Picatinny Arsenal: " For howitzers firing at relatively low velocities, the life of the gun barrel is about 12,000 rounds and there is no advantage in plastic bands because of the very long

life of the barrel. For anti-aircraft weapons firing at 2800 fps with a barrel life of 3000 rounds, plastic bands increase the barrel life by 2 to 3 times. In the case of automatic 20 mm weapons, the barrel gets very hot and it is assumed that barrel wear is due to a large extent to swaging of the bore. Plastic bands causing much lower band pressure than metal ones increased the length of the permissible burst by a factor of several times."*

17. Published reports and verbal information indicate that the present British performance requirements for plastic rotatings bands are as follows:

a. Satisfactory spin must be imparted to the projectile to give it stability in flight.

b. The band must be reliably retained on the projectile after it leaves the gun barrel. The principal reason for this requirement seems to be the protection of nearby personnel. The Air Force is also concerned with the possibility that fragments from bands which fail may be picked up by jet intakes.

c. The band must perform satisfactorily after standing in a hot gun. This requirement seems to have special reference to the fact that anti-tank weapons have to be kept loaded and ready to fire on very short notice. No convincing reason for this requirement in other instances was advanced. Specific standards of time and temperature in connection with this requirement are somewhat in dispute. Such standards naturally cannot exceed in severity the conditions which the propellant and/or the explosive can stand.

d. Satisfactory performance must be obtained after standard storage. Standard storage is defined by War Office Policy Statement 100 which specifies that equipment shall withstand storage at 140°F to -50°F and shall operate successfully at 125°F to -25°F. To meet this requirement, the British use a 3-month storage period at 140°F and 95 to 100% relative humidity. However, as Col Flowerdew of the Armament Design Establishment (ADE) points out, 90°F and 90% relative humidity may exist for months on end at a place like Singapore but at any place where the temperature rises to 120°F, the relative humidity will drop to about 20%. Therefore, ADE prefers to be guided by actual storage tests in Nigeria.

e. The plastic-banded projectiles must be usable in both new and worn weapons. This is a problem which can be solved only through design modifications.

In the United States

Franklin Institute

18. Since July 1946 Franklin Institute has performed research and development work for the Ordnance Corps under

*Quoted from Item 32 of the Bibliography contracts relative to several phases of Project TA1-5005, the subject of which is: Long Range Program of Basic and Technical Research for Improvement of Artillery Ammunition and Material. In the beginning, technical supervision of these contracts was handled by ORDTA. In 1952, this supervision was transferred to Watertown Arsenal. Development of plastic rotating bands is one phase of this work.

19. Results of preliminary studies concerned with rotating bands in general, rifling, friction, and time-travel (Item 34 of Bibliography) indicated that plastics could be considered as potential substitute materials for the copper alloys used generally in rotating bands. A direct substitution with no design modifications of either the projectile or the gun was aimed at. The first approach was essentially Edisonian, that is, trial and error. The following materials were evaluated as rotating bands for .50 caliber rounds: Teflon, Nylon 6.6, vulcanized fiber, lignin resin, and vinylite. Firing test results were encouraging. All bands came off outside the muzzle, but most bands produced good spin, velocity, and accuracy. In erosion firing tests, vulcanized fiber surpassed all other band materials including metals. Teflon was too weak, and the other materials were fair (Item 35 of Bibliography).

20. In 1949, work was begun on the development of bands for 75 mm recoilless rifle ammunition. For reasons of economy and convenience, 20 mm prototype projectiles were used in this work. On ORDTA's request, the Naval Ordnance Laboratory selected and molded directly on the projectile 10 materials covering a wide range of properties. Two of the 10 plastics were found to be promising band materials for the 75 mm projectile (Item 36 of Bibliography).

21. During the following years, increased emphasis was placed on the evaluation and testing of moldable plastics. Static and dynamic engraving tests were performed on a number of materials. Picatinny Arsenal assisted by studying physical properties, effect of temperature variations on the physical properties, dimensional stability, and fabricating methods.

22. At this stage, an ethyl cellulose formulation and Nylon 6.6 looked most promising. Both 75 mm and 105 mm recoilless rifle projectiles with ethyl cellulose bands were fired at -65°, 70°, and 160 °F with good accuracy. No damage to the thin-walled barrels from band pressure was observed. The conclusion was reached that unengraved bands of several plastics tested are suitable for use on ammunition for recoilless rifles which have been provided with forcing cones (Items 37 and 38 of Bibliography).

23. During 1952, 1953, and 1954, over 40 different plastics were tested on the 20 mm scale. Type and amount of propellant; projectile, band, and barrel design; and firing conditions were kept

the same in all firing tests. Thus, the only variable was the band material. During this period, the materials tested at Franklin Institute were selected by the cooperative efforts of SF '', and NOL. These two facilities also provided the molded bands (Fig 1). Materials were

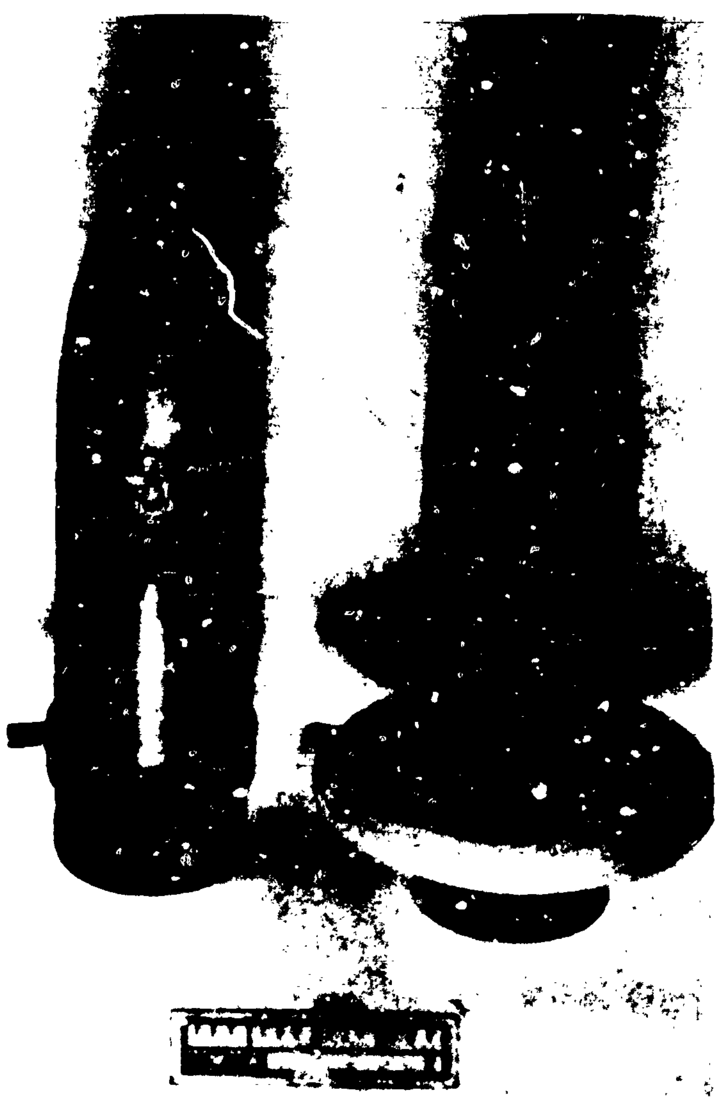

Fig 1 Plastic Rotating Bands Before Machining to Design Dimensions

chosen either because they possessed certain properties which made them appear promising for this application or because they were representative of particular types of plastics. Suitability for use as rotating bands was judged by the ability of the bands to impart spin, to obturate, and to be retained in flight.

24. Additional work on methods of mounting the plastic bands, barrel wear, design parameters, and engraving characteristics was started, but had to be suspended because of curtailment of contract funds (Items 39, 40, 41, 44, and 45 of Bibliography).

25. On several occasions, work on the development of end items was also performed. A test firing of 105 mm howitzer ammunition with plastic bands was conducted at Jefferson Proving Ground. Two nylon compounds performed well. A study of nylon bands for the 27 mm T142 practice projectile was undertaken. The results indicated that nylon bands would meet the rotational requirements, but that further experimentation would be needed to solve the problem of band retention. When used with 57 mm recoilless rifle ammunition, both ethyl cellulose and nylon bands (Fig 2) gave performance comparable to that of pre-engraved metal bands. The firing test demonstrated, however, that the band design was not optimum with regard to band pressure and band retention (Item 42 and 43 of Bibliography).

26. Plastics reinforced with glass fibers had not been tried for rotating bands, because it was reasoned that the rough ends of the fibers would have an abrasive effect and cause excessive barrel wear. To prove or disprove this theory, Picatinny Arsenal provided 1400 rounds of .50 cal. projectiles with

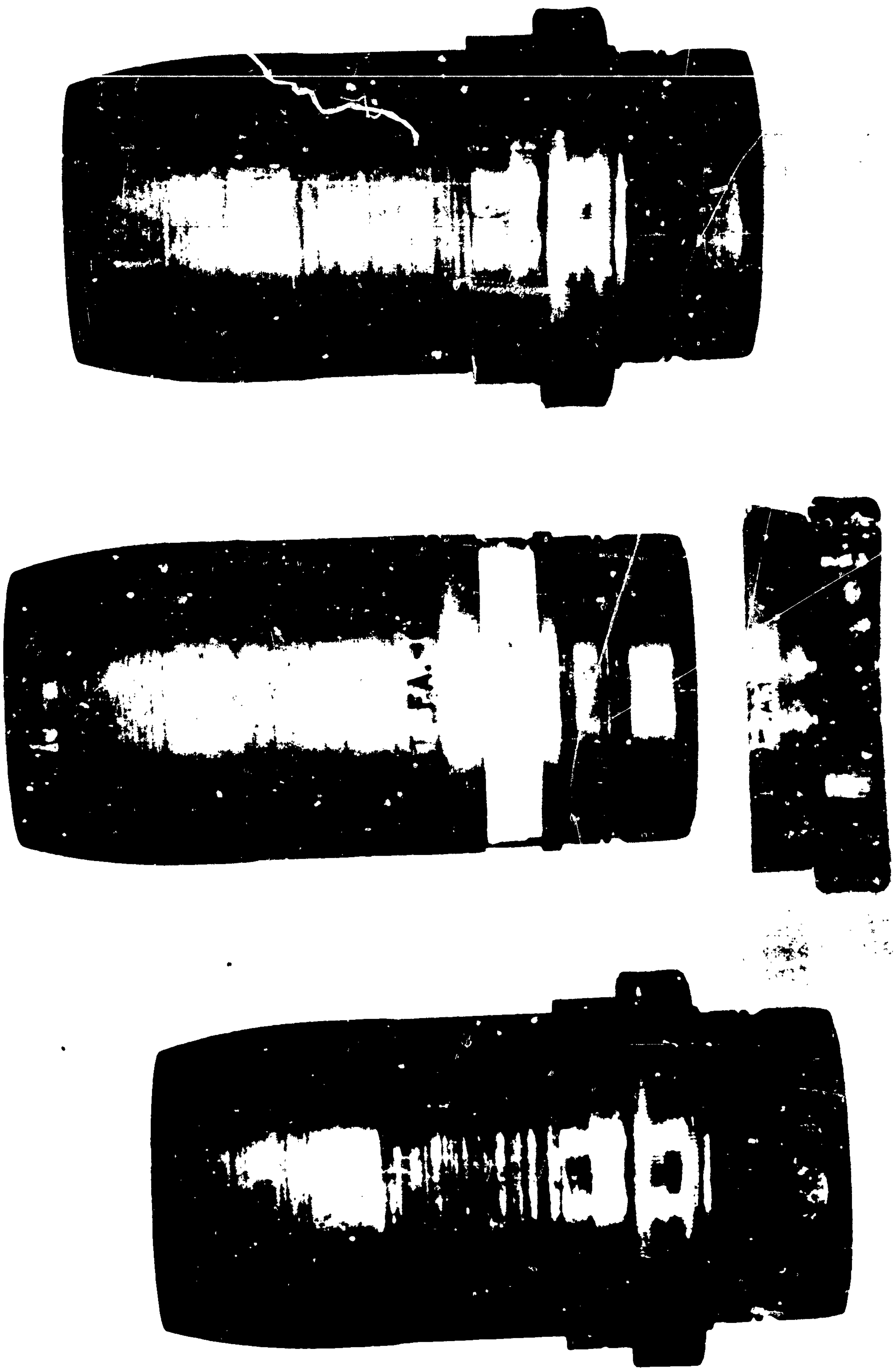

Fig 2 57 mm Shell with Ethylcellulose Bands Molded at SFAL for Franklin Institute bands molded of glass fiber-filled polystyrene. Contrary to all expectations, when the 1400 rounds were fired, gun tube wear was not excessive and perhaps even slightly less than that produced by nylon (Item 45 of Bibliography).

Naval Proving Ground and Naval Ordnance Laboratories

27. The Naval Ordnance Laboratories (NOL) became interested in plastic rotating bands in 1949, when they were asked, by Franklin Institute, to assist in the selection and molding of plastics for rotating bands. Shortly afterward NOL cooperated with the Naval Proving Ground (NPG) in the development of plastic bands for ammunition for the 3"/50 and 3"/70 guns. This interest in plastic rotating bands, in the case of the Navy, was motivated mainly by desire to reduce gun barrel wear.

28. In contrast with other facilities working on the development of plastic rotating bands, NOL and NPG discontinued the search for optimum materials and concentrated on Nylon 6.6 (Zytel 101) as soon as preliminary tests at NOL and Franklin Institute had indicated a certain superiority of nylon over materials then available. All efforts were thereafter concentrated on the improvement of designs and the development of optimum molding techniques for nylon bands.

29. Conditions on board naval vessels make the retention of rotating bands in flight essential. Consequently, once a plastic was found from which bands could be made that imparted full spin and obturated satisfactorily, efforts were concentrated on the problem of preventing the bands from flying off. This was achieved, after much experimentation, by adopting a bandseat design which by means of dovetails held the bands firmly in the seat even at hypervelocities. It was realized that such other factors as the profile and width of the band and the molding conditions are also important, and that optimum designs and conditions would have to be found (Items 47, 52, 53, and 54 of Bibliography).

30. Satisfactory nylon bands were also designed by NPG for the 5"/3.75" discarding sabot round and the 60-lb 5"/54 HC Round (Items 56, 57, 58, and 61 of Bibliography). Substantial efforts were made to develop plastic bands for 20 mm high velocity projectiles. A new band design and an improved method of molding were developed which provide bands that are retained in flight under all firing conditions. In these test firings, velocities of up to 4000 fps were used. Rapid-fire results obtained with a high performance Mk 12 gun showed that satisfactory performance of the band is obtained even in a very hot gun. Results of artificial aging and storage tests under extreme conditions of temperature and humidity indicated that the storage life of these nylon bands under service conditions would be adequate. Contrary to all expectations, the bands performed satisfactorily even though test specimens molded under identical conditions and exposed to the

same storage conditions showed a marked deterioration of their physical properties (Item 49, 53, 55, 59, and 60 of Bibliography).

31. When the practicability of nylon (Zytel 101) bands for small and medium caliber artillery ammunition had been proved, other plastics were investigated at NOL on the 20 mm projectile. Good results were obtained with bands made of a rigid polyvinyl chloride (Geon 8700A), a styrene terpolymer (Cycolac), and a polycaprolactam (nylon BN-3). These bands were tested over a broad range of temperatures and at velocities of up to 4000 fps (Items 50, 51, and 60 of Bibliography).

Picatinny Arsenal

32. In 1951, Picatinny Arsenal was assigned by OCO the task of assisting Franklin Institute in the development of plastic rotating bands. Picatinny's contribution consisted essentially of selecting and testing a variety of plastics which adequately covered the types of materials available without either duplicating similar types or omitting significantly different types. From 100 to 200 rotating bands were fabricated from each selected material and mounted on 20 mm shell. The majority of the bands were molded directly onto the shell (Figs 1 and 2), but other means of fastening, such as heat shrinkage, swaging, casting, and winding, were also investigated. All banded shell were submitted to Franklin Institute for evaluation.

33. Efforts were made to correlate physical properties with band performance. The conclusion was reached that no single property can be used to predict completely the behavior of a band material. It became apparent, moreover, that the dimensions and configurations of the band, the band seat, the chamber, the barrel, and the rifling are important factors. All must be adapted to each particular band material if optimum results are to be obtained.

34. These conclusions were reached by the Navy investigators at an early stage of their development work on plastic rotating bands. Therefore, to narrow the scope only one promising material, Nylon FM-1001 (now Zytel 101), was chosen by NOL and applied to two projectiles, one for the 3"/50 gun and one for the 20 mm gun Mark 12. These investigations demonstrated that by modification of the design of the band and band seat, nylon bands can be produced which will impart the desired ballistics; be retained in flight; and, by reducing barrel wear, will lengthen gun life substantially. Difficulties were encountered, however, because of poor dimensional stability of the particular nylon compound used.

35. To avoid duplicating work performed by the Navy investigators and in recognition of certain serious shortcomings of Nylon 6.6, Franklin Institute and Picatinny Arsenal (PA) confined their investigations to other materials which appeared to be similar or superior

to the most promising of those already tested. From the results obtained, it appears that there are a number of plastics suitable for rotating bands even though no one material available at the present time can be said to possess all the desirable properties of an ideal rotating band. Thus, it remains for the design engineer to select band materials by selecting the particular combinations of properties and the particular band and band seat design which will give optimum performance for the particular type of ammunition and/or weapon in which they are interested.

36. The results of the work performed at Picatinny in cooperation with Franklin Institute have been recorded in several reports. Of particular interest are a report titled "A Survey of Plastics for Rotating Bands" prepared by The Franklin Institute for Watertown Arsenal Laboratory, WAL 760/452-19 (Ref 40) and the discussion of the properties of plastics contained in Picatinny Arsenal Technical Reports 1898, 2335, and 2382 (Items 63, 64, and 65 of Bibliography). Fabrication and fastening methods are detailed in Picatinny Arsenal Plastics Laboratory Reports 53-M2-100 and 54-M2-21 (Items 66 and 67 of Bibliography).

37. To facilitate the exchange of technical information among active investigators in this field, two major conferences were held, one in 1951 in Watertown Arsenal and the other in 1954 at Picatinny Arsenal. The minutes of these conferences were recorded and published (Items 46 and 62 in Bibliography).

38. In the preceding sections of this report, an attempt has been made to give the reader a condensed picture of the work performed in the development of plastic rotating bands by the different installations concerned with this problem. Most of this work has already been reported in detail elsewhere. (See annotated bibliography beginning on page 54 of this report.) More recent investigations at Picatinny Arsenal, not covered by the reports listed in the bibliography, are described in the next section of this report.

RECENT MATERIALS INVESTIGATIONS AND DEVELOPMENT WORK AT SFAL

Materials Studied

39. On the basis of the findings of a general investigation of plastics in terms of their suitability as materials for rotating bands, Picatinny Arsenal concentrated on a thorough investigation of a few of the most promising materials. Six of these materials (See Table 1, p 12 for sources) are discussed below.

Nylon 6.6

40. Properties and molding methods for Nylon 6.6 have been throughly investigated by British and United States Navy Ordnance facilities (Items 6 and 49 in Bibliography). In firing tests, good

TABLE 1

Sources of Materials

Designation	Trade Name	Manufacturer
Nylon 6.6	Zytel 101	E.I. DuPont de Nemours & Co. Wilmington, Del.
Nylon 6	Plaskon Nylon 8200	Barrett Division Allied Chemical & Dye Corp. NY 6, N.Y.
Polyurethane U	Durethane U	Farbenfabriken Bayer, A-G Leverkusen, Germany
Rigid PVC Type I	Geon 8750	B.F. Goodrich Chemical Co. Cleveland 15, Ohio
	Boltaron 6200	Bolta Products Div of the General Tire & Rubber Co. Lawrence, Mass.
	Geon 8700A	B.F. Goodrich Chemical Co. Cleveland 15, Ohio
	Boltaron 7200	Bolta Products Div of the General Tire & Rubber Co. Lawrence, Mass.
Cycolac	Cycolac 12830	Marbon Chemical Div of Borg-Warner Corp. Gary, Indiana
Polyethylene (Low Pressure Processed)	Marlex 50	Phillips Chemical Co. Bartlesville, Okla.

ballistic results have been obtained with nylon bands on 20 mm, 76 mm, and 83 mm projectiles. However, several difficulties, especially with regard to inspection methods and occasional inconsistencies in performance, have still to be overcome. Except for a few experimental end item applications, very little development or testing work on Nylon 6.6 has been performed at SFAL, since such work would only duplicate work performed at NOL. Being aware of the several shortcomings of Nylon 6.6, Picatinny has continued the search for and the investigation of other plastics with strength and toughness properties similar to those of Nylon 6.6 but possibly with fewer disadvantages.

Nylon 6

41. Among other polyamides that could be considered for this application Nylon 6 (polycaprolactam) has strength properties very similar to those of Nylon 6.6. These properties and their variations with temperature were thoroughly checked at Picatinny. NOL has fired 20 mm projectiles banded with Nylon 6 at high velocities with good results (Item 50 of Bibliography). However, since the water absorption of Nylon 6 is even higher than that of Nylon 6.6, no advantage is seen at present in the use of this material.

Polyurethane U

42. This new moldable thermoplastic based on the poly-addition of a dibasic alcohol (1, 4 butanediol) and a straight linear urethane is in many ways similar to Nylon 6.6. Essential differences are that Polyurethane U absorbs considerably less water and melts at a lower temperature than Nylon 6.6. Detailed information on the properties of this material are given in Item 64 of the Bibliography. As far as can be judged from the results of the tests performed, it can be considered promising as a material for rotating bands. Firing tests of 37 mm projectile with molded polyurethane bands are described in paragraphs 65 through 75.

Polyvinyl Chloride (PVC)

43. Unplasticized rigid PVC compounds introduced after World War II have important advantages in mechanical toughness, moisture resistance, corrosion resistance, and behavior at low temperatures when compared with other available plastics. Early in its work with plastic rotating bands, SFAL became interested in PVC. The workability of the first lots of this material available in the United States was, however, rather poor. During recent years, improvements in polymerization techniques and the development of better stabilizers have made available rigid PVC compounds which can be formed by calendering, vacuum-forming, extrusion, compression, and transfer-molding. Injection molding became possible also with the development of special machines which embody what is essentially a combination of the extrusion and injection processes.

44. The first PVC bands were transfer-molded at Picatinny as early as 1951.

Next to nylon bands, they looked most promising in firing tests at Franklin Institute. The cumbersome fabrication methods and toxic stabilizers then used hindered a more general use of this material at that time. Better compounds and more economical fabrication methods were developed during the following years. As soon as these improved compounds became available, they were thoroughly investigated at SFAL and the results were reported (Item 65 in Bibliography). Fabrication methods are discussed in paragraphs 52-64 below, and the results of firing tests in paragraphs 65-75.

Cycolac

45. This particular styrene plastic is a relative newcomer in the field. It has been available only for the last two years. Because of their inherent brittleness, straight polystyrene plastics cannot be used for certain applications requiring toughness. Mixtures of polystyrene with elastomers like GRS and Buna N have excellent toughness and impact strength, but these materials have given only a fair performance when used for rotating bands. Cycolac is a terpolymer of acrylonitrile, butadiene, and styrene, not a blend of resins and rubber or plasticizers. The manufacturer states that it is a single material of uniform molecular structure. An inspection of its mechanical properties, as determined by standard tests did not indicate that this compound would have more than fair suitability for rotating bands. But, in the few firing tests that were performed by NOL and SFAL, Cycolac bands not only gave good ballistic performance but also had excellent stay-on properties. Approximately 50 rounds were fired, and not a single band was discarded. More extensive tests of this material should be undertaken.

Low Pressure Polyethylene (Marlex 50)

46. When tried in early experiments at Franklin Institute, standard polyethylene gave good performance at low velocities but did not function properly at 2700 fps. Recently developed low-pressure-processed polyethylenes have higher strength, are harder, and have higher softening temperatures than the standard types. These low-pressure polyethylenes, like all new products, are being investigated in the plastics laboratory at Picatinny. It was considered worthwhile to give one such material, Marlex 50, a tryout as rotating band material. Detailed results may be found in paragraph 73. Like standard polyethylene, Marlex 50 failed when velocities were increased, the point of failure being in this case 2300 fps.

Investigations of Properties

47. The seven plastics discussed in the preceding paragraphs are compared, in terms of some of their more commonly reported properties, in Table 2 (p 15). The tensile properties of the nylons vary widely depending on their water content. The ranges within which the readings obtained at SFAL fall are given in the Table. Since water absorbed by nylon acts as a plasticizer and affects

TABLE 2

Physical Properties of Seven Plastics Investigated at Picatinny Arsenal

	Nylon 6.6 (Zytel 101)	Nylon Polycaprolactam	Poly urethane U	Polyvinyl chloride, Type I	Polyvinyl Chloride, Type II	Cycolac (Styrene Terpolymer)	Marlex 50 Low Pressure Polyethylene
Tensile strength, psi							
−65°F	15,000	18,000	14,000	16,000	12-14,000	8,200	7,300
+73.5°F	8-11,000	8-11,000	7,600	8-9,000	6-7,000	5,000	4,300
+160°F	8,000	6,000	4,600	2-3,500	2-3,000	2,700	2,100
High speed tensile strength (approx 0.007 sec to break), psi			9,500	16,000	14,000	8,000	8,500
Elongation at 73.5°F							
at yield, %		4-18	16	3-5	3-5	3	15
at failure, %	3-200	35-225	37				22
Tensile modulus, psi	300-400,000	200-420,000	222,000	420-500,000	300-420,000	240,000	151,000
Hardness, Rockwell R	116	108	111	81-85	76-82	85	65 Shore D
Heat distortion at 264 psi, °F	150	145	170	160-165	155-160	183	136
Maximum water absorption, %	to 9	to 12	to 2.5	0.1	0.1	1.0	0.1
Izod impact, ft lb/inch of notch at 73.5°F	0.8-1.5	1.3	0.9	0.8-1.0	5-15	4	3
Specific gravity	1.14	1.13	1.20	1.3-1.5	1.3-1.5	1.01	.965

the mechanical properties of the plastic, water absorption is, in the opinion of the author, the main reason for inconsistencies noted in the firing results. In the case of PVC, the ranges given represent variations among products of the same type obtained from different manufacturers.

48. In contrast with metals, plastics are very temperature and time sensitive. For this reason, variations of plastics with temperature, age, and environment must be closely checked. Records of observed variations of this kind are kept on file at SFAL. From time to time, technical reports reflecting these findings are published (Item 63 and 68 in Bibliography). Variations of mechanical properties with rate of load application are great for some plastics and small for others. For certain Ordnance applications, as for rotating bands, loads are applied to plastic components at ballistic velocities. The effect of variations in the rate of load application upon the mechanical properties is therefore of extreme importance.

49. Ballistic velocities are normally not encountered in civilian applications and practically no attempts had been made in the past to study the behavior of plastics under such conditions. To obtain this vital data, it was necessary to develop special apparatus to measure properties of plastics at high loading rates. Apparatus to measure the tensile strength of plastics at high rates of loading (failure in as little as 5 milliseconds) has been constructed and is now in operation at Picatinny. Detailed results of high speed tests of several rigid PVC compounds have been published (Item 65 in Bibliography). A report describing the apparatus and the method used to measure the loading rate is in preparation.

50. It was hoped that the collection of comprehensive data on the physical properties of the various plastic materials would make possible the correlation of physical properties with performance as rotating bands. Such a correlation, would lead to a more exact definition of the physical requirements of rotating band materials.

51. However, considering the complexity of actual service in which a variety of different critical conditions may occur, it appears unlikely that any one simple property can provide an accurate index of serviceability. This was born out by an examination of the properties of over 50 different plastics which were considered as possible rotating band materials. The underlying cause may be found in the fact that the forces acting on a rotating band are not as in general testing procedures uniaxial, but are a combination of torsional, compression, and tensile stresses all of which act on the band almost simultaneously, within a couple of milliseconds.

52. It is usually necessary to give weighted consideration to several basic properties in judging the potential

suitability of a material for a given application. In the case of plastic rotating bands, the most promising materials were found to have the following combination of properties:

A reasonably high modulus of elasticity of 250,000 to 500,000 psi at 73°F.

A substantial increase in tensile strength with any increase in rate of load application.

A Rockwell hardness of R85 to R120

A softening temperature which is as high as possible

A water absorption which is as low as possible

Methods of Fabrication

53. Next to plentiful supply and certain outstanding physical properties, ease of fabrication is one of the main advantages of plastics over metals. In the present case, several ways of fabricating and mounting the plastic rotating bands were found feasible and were tried.

54. Two methods used by early experimenters have been discarded as unsuitable. One consisted of cementing a molded thermosetting plastic or hard rubber (ebonite) cup to the base of the projectile, with the sidewalls of the cup acting as a rotating band. By the other method, a molded or machined band was softened by heating, slipped over the base of the projectile into the band seat, and there it tightened by shrinkage during cooling. The base cups consistently discarded and the heat-shrunk bands frequently slipped in the seat and for that reason failed to impart sufficient spin to the projectiles. Three other methods which have been used at Picatinny and elsewhere are described below.

Molding of the Band Directly to the Projectile

55. In this method, the projectile is used as a mold insert and the plastic band is molded around it. Transfer molding is used for thermosetting materials and injection molding for thermoplastics. With multicavity molds and proper mold design,bands can be molded to final design dimensions at a fair rate of speed. Very little finishing work is required. For experimental purposes, the bands are usually molded oversize and then machined to the desired dimensions (Figs 1 and 2). One serious drawback, especially when it comes to the larger calibers, is the amount of material that must be handled and the size of the mold and the molding machinery required.

56. A variety of bands, from both thermosetting and thermoplastic materials, have been molded by SFAL on 20 mm and 57 mm projectiles for Franklin Institute (Ref 67). For recent tests performed at SFAL, Polyurethane U and Cycolac were injection molded on 37 mm projectiles.

Swaging by Means of a Rubber Die

57. Injection molding requires elaborate machinery and molds. Some thermoplastics are very difficult to injection mold. Moreover, the materials handling sequence--from steel mill to machine shop to plastic molder to loading pla- -is cumbersome and expensive. If one or several of these steps could be eliminated or simplified, this would bring about considerable savings in time and cost. With this reasoning in mind a swaging method was devised by this laboratory.

58. Extruded polyvinyl chloride pipe, because of its toughness and corrosion resistance, has found widespread use in industry and has therefore become a standard stock item. It was an easy matter to cut this commerically available pipe into bands. When heat softened, these bands could easily be slipped over the base of the projectile and into the band seat. At this stage, however, the difficulties started.

59 For better band retention, band seats with undercuts or dovetails had been developed. The problem now arose of how to force the slipped-on band firmly into the contours of the band seat. Upon cooling, the slipped-on band contracts somewhat but not enough to fill out completely the undercuts of the band seat (Fig 3, bottom p 19). It becomes necessary to apply additional external pressure to seat the band firmly in the band seat. Such external pressure has to be radial in direction and uniform at all points around the perimeter of the band. Considerable difficulties were experienced in providing such a pressure. Three possible methods were investigated:

Compressing the band in a compression mold

Compressing it with a tire-setting machine

Compressing it with a rubber-swaging die

The first method proved to be too time-consuming, and, when the second was used, stress concentrations and cracks occurred in the bands. The third method which is a modification of the rubber crimping die process, was most successful. Rubber crimping dies have lately found extensive use for crimping cartridge cases over shell bodies (Item 69 in Bibliography). Making use of this principle, a special rubber die (Fig 4, p 20) was designed and built.

60. This rubber swaging die operates in the following manner: A vertical downward force is applied on the rubber ring, compressing it. When under compression, rubber behaves essentially like a fluid. Consequently, since movement of the rubber downward, upward, and outward is prevented by the walls of the steel die, the rubber moves inward. This inward movement creates a uniform, radial pressure around the perimeter of the band and causes the plastic which has been heated to 220-250°F to flow into all the contours of the band seat. Temperature, pressure and dwell time vary for

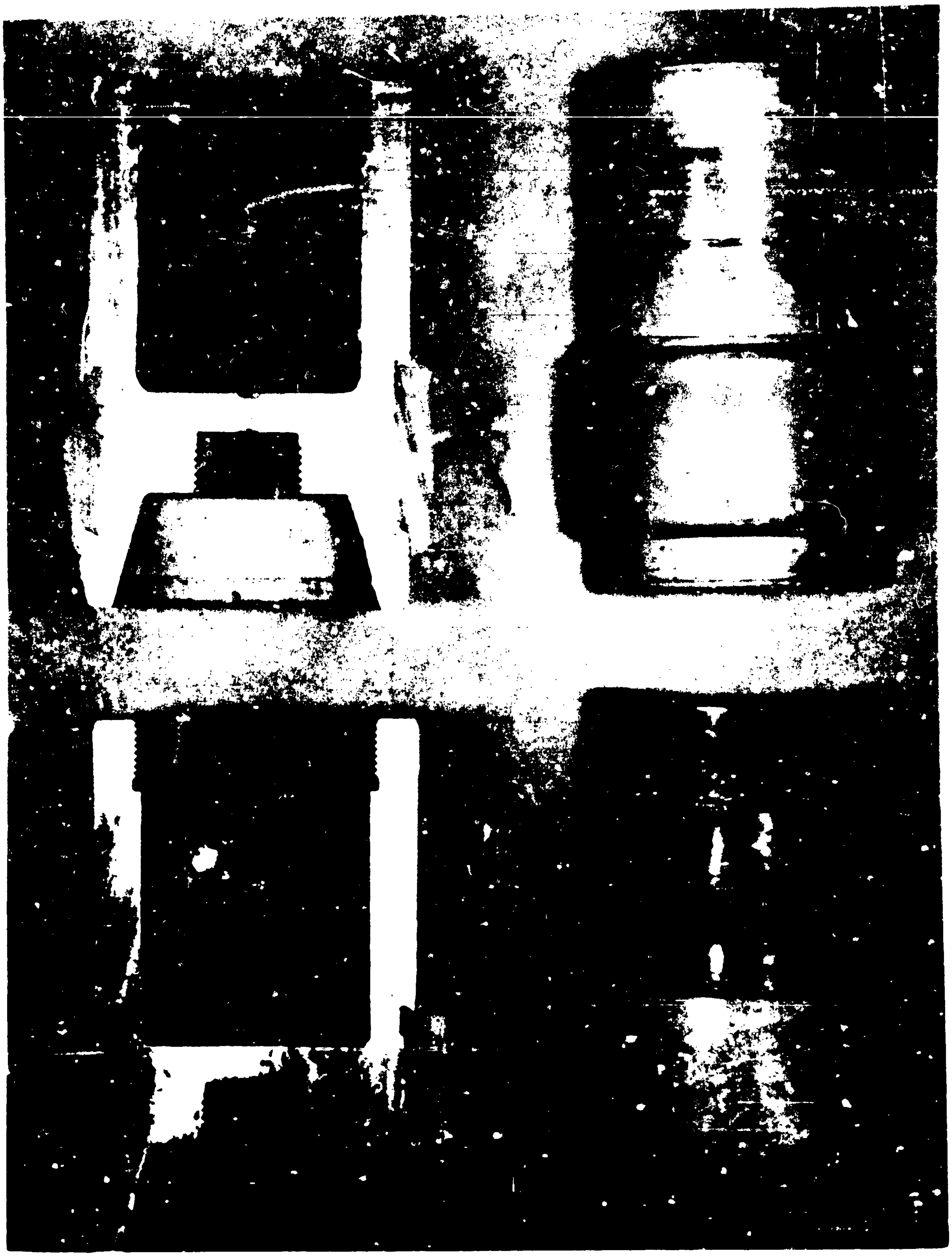

Fig 3   Two Methods of Assembling Bands to Shell: (1) Slipped on and heat shrunk, and (2) Swaged in rubber die. Note now, under (2) all undercuts are filled out.

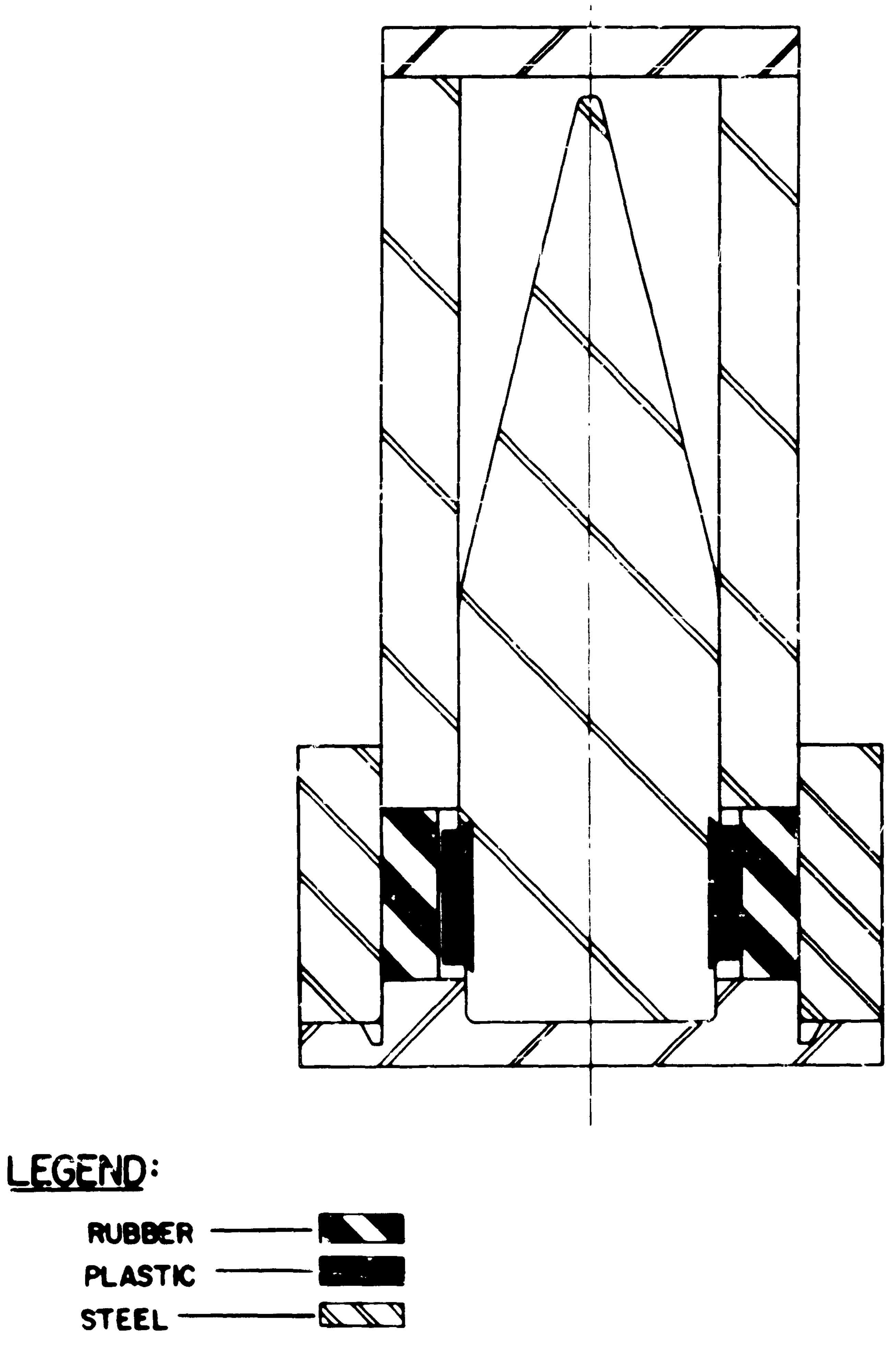

Fig 4 Swaging Die

different plastics and band sizes. In the case of PVC bands for the T290 shot, the following conditions gave good results:

Temperature of band and projectile	220°F
Temperature of die	Ambient
Pressure on rubber die	5000 psi
Dwell time	45 seconds

For further details, see pp 118-144 of Item 62 and Item in Bibliography; also Figures 3, 4, 5, and 6.

61. This method has been used at Picatinny Arsenal to attach PVC rotating band to 20 mm test projectiles for Franklin Institute and NOL, to 76 mm T290 shot and to 90 mm T249 HEAT shell for test firings at Aberdeen, and to 37 mm M74 shot for local testing. The latter tests are discussed in paragraphs 65-75 of this report.

62. Only PVC bands have been mounted by this method in the past. The reason for this is simply that PVC pipe is a standard commercial item. Other plastics like Cycolac, which must be specially extruded into pipe of an appropriate diameter, will be tested at some future date. The nylons have too high a softening point to be used in rubber dies.

63. The rubber die method of swaging the bands has one big advantage: it can be performed right in the machine shop where the shell or shot are manufactured. The dies are of very simple construction and can be made by any skilled lathe operator; only low heat (220 - 250°F) need be applied to the projectile and band; and the swaging operation can be performed on a simple hydraulic press of appropriate size. Nor is any special skill required to perform these operations. Operators can be trained within a few hours.

Screw-on Bands

64. The desire to eliminate the need for injection molding led also to the simple approach of providing the projectile with outside threads and the band with inside threads and screwing the band onto the projectile. It is fully realized that threading considerably weakens plastic components, the effect being similar to that of notching an impact test specimen The first projectile on which this method of fastening was tried was the 90 mm HVAPDS T137. Since this round has a discardable sabot, the discarding of the band is permissible. No break-up of bands was experienced inside the gun. Only Nylon 6.6 was considered and used for the T137 round.

65. Any of the following three methods of fabrication may be used for this particular band:

Machining from extruded pipe

Machining from injection-molded blanks

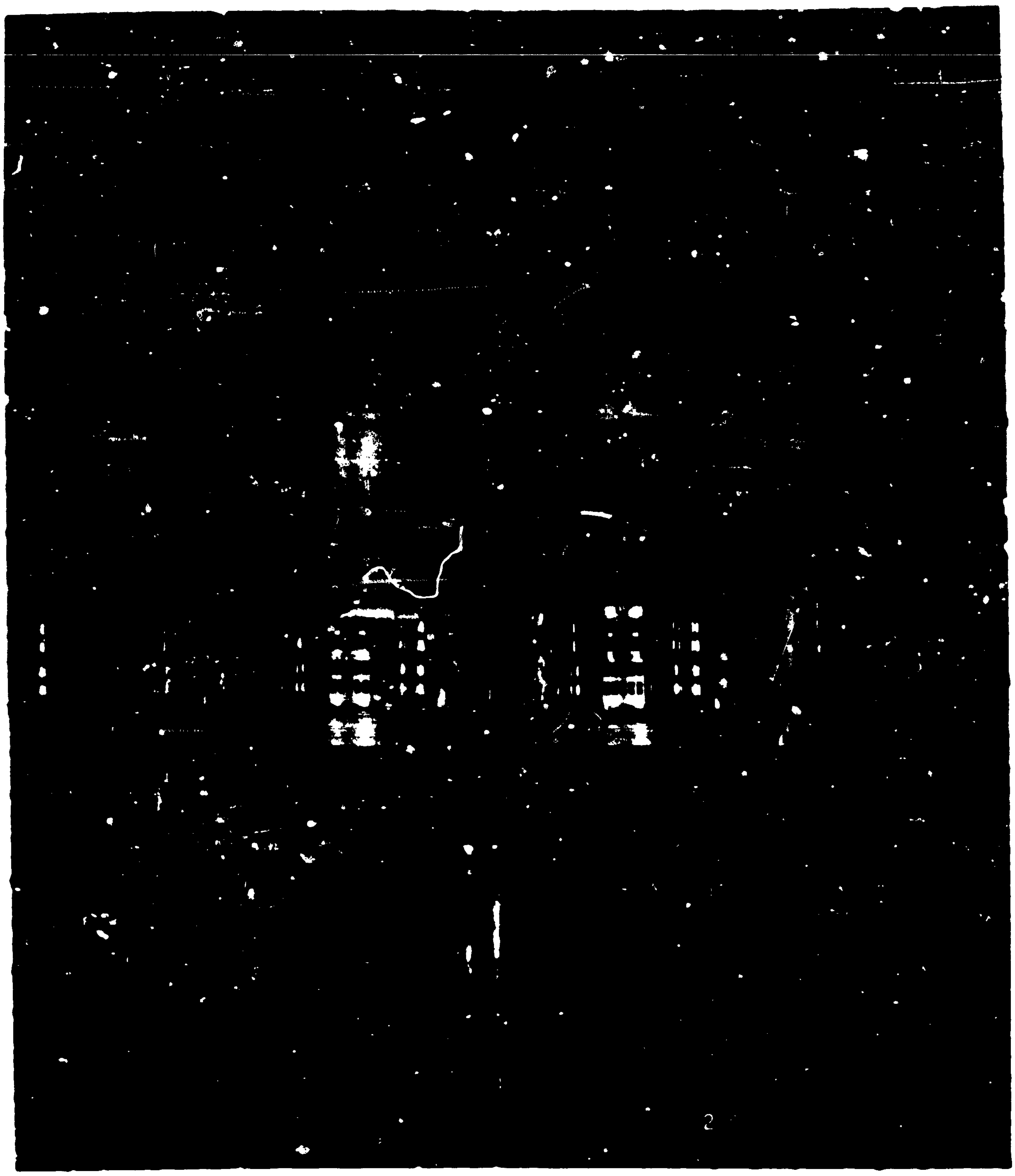

Fig 5 76 mm HVTP Shot With Swaged PVC Bands, with Sections of Bands Removed to Show Band Seams: (1) Type A, and (2) Type B

Fig 6 76 mm T290 HVTP Shot with Swaged PVC Band, after Machining

Injection molding to semi-final or final dimensions

For mass production purposes, it would appear that injection molding would be the most economical method. However, the cost of multicavity molds constructed to produce end items which must meet close tolerances and have inside threads proved to be prohibitive for small experimental lots. Machining from extruded pipe would be next in cost or possibly cheaper than injection molding, even in mass production. For the time being, no extruded nylon pipe of so large a diameter is in commercial production. It is foreseen, however, that extrusion techniques for nylon will be improved in the near future to permit extrusion of larger diameter pipe. It will then be possible to machine rotating bands at relatively low cost on automatic lathes from 10-to 20-foot sections of pipe. At the present time, only 1-ft lengths of molded pipe are available, and costs are rather high. Most of the bands tested so far have been individually machined from injection-molded blanks. Results of some firing tests with screw-on bands are given in paragraph 89 of this report.

Firing Tests

66. At a conference of representatives of Frankford, Watertown, and Picatinny Arsenal held in May 1954, it was decided to use the 37 mm gun system for as much of the basic development work on all rotating bands as possible. The following reasons were given:

a. It provides a common basis for comparing the different types of bands.

b. Preliminary firing tests can be conducted at all facilities.

c. The 37 mm projectile is economical as a test vehicle and at the same time suitable for use as prototype for larger projectiles.

67. Pursuant to this decision, 300 standard 37 mm M74 AP shot, were procured. Their gilding metal bands were removed and new band seats were machined according to a design similar to the one used successfully by NPG on the 20 mm and 3"/50 rounds (Fig 7, p 25). A study of the chamber dimensions of the M3 gun revealed that a band wider than the .74 inch standard metal band could be used. For the plastic bands two widths were chosen, .775 inch and .900 inch. A two-cavity injection mold and a swaging die were designed and constructed. One hundred eighty-five plastic bands were then fabricated as follows:

50 of injection molded polyurethane U

20 of molded Marlex 50 polyethylene

25 of molded Cycolac

30 of swaged Geon 8700A (PVC Type III)

30 of swaged Boltaron 6200 (PVC Type I)

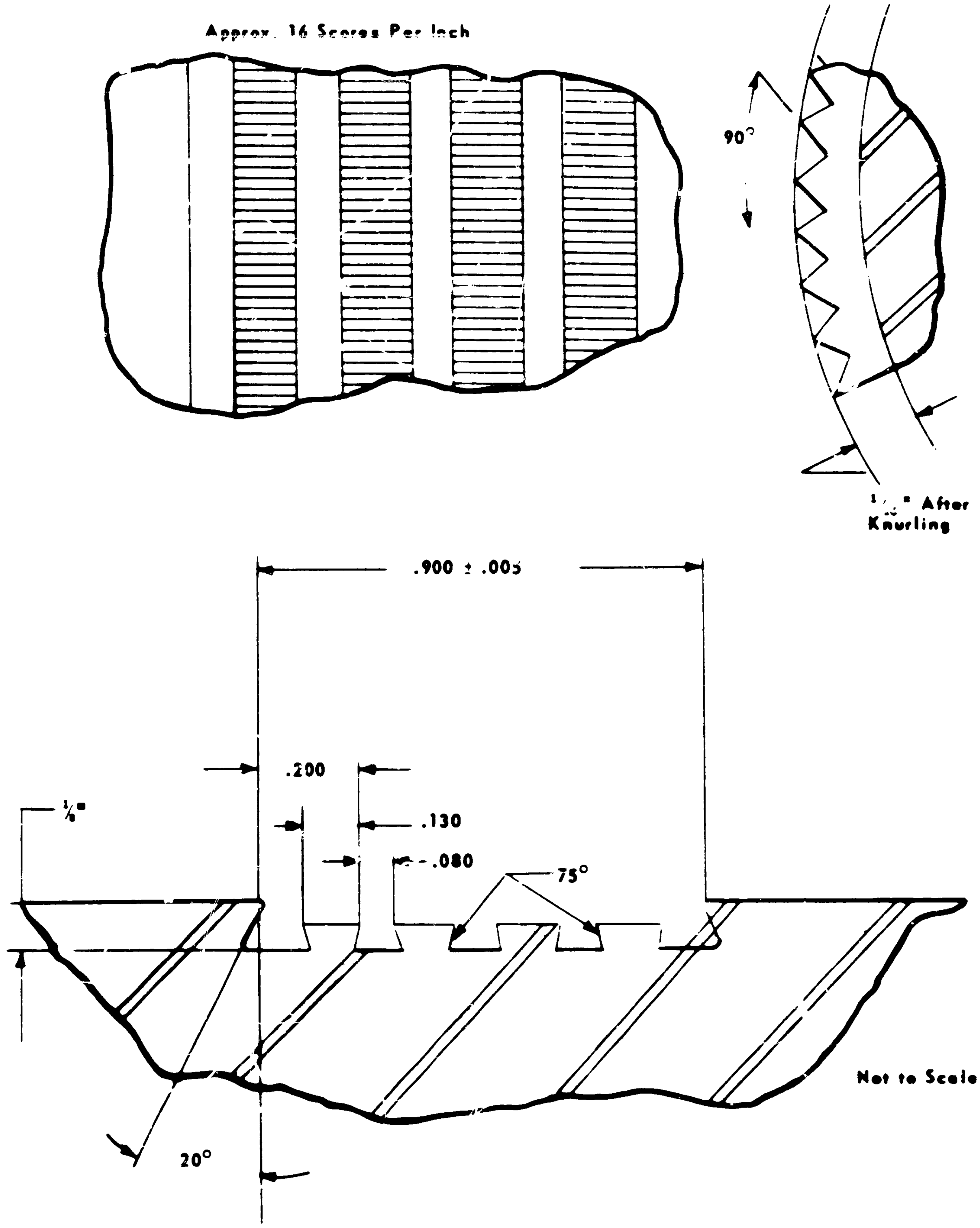

Fig 7 Detail of Modified Band Seat for 37 MM M74 Shot with Plastic Rotating Bands

30 swaged of Boltaron 7200 (PVC Type III)

All of these bands were fabricated oversize and, after mounting, machined to final dimensions.

68. For reasons of expediency and economy the test firing of these 37 mm projectiles with the above-mentioned plastic bands was arranged locally. At the Picatinny Arsenal Rocket Test Station, small caliber artillery projectiles can be fired over a range of 150 to 200 feet into a tunnel. All types of up to date instrumentation used for rocket and jato testing are available.

69. Preliminary tests were performed in October 1954. Only velocity, pressure, and yaw could be determined then. Recovery was tried, but it was observed that frequently bands were damaged by the recovery setup and came off inside the recovery boxes. It was decided then to discontinue recovery and to try the taking of flight pictures as a means of determining whether the bands were retained.

70. As was brought out earlier in this report, the primary function of a rotating band is to impart spin to the projectile. It is therefore essential that rate of spin be determined when rotating bands are tested. The methods commonly applied in the past at proving grounds are: the crossed wire method, the pop-out pin method and the photographic method. All of these methods require considerable preparation between rounds, modifications of the shell, and expenditures for expendable equipment. Consequently, tests performed by these methods are expensive. Another method, called "magnetic coupling," was recently introduced by the British and improved by Franklin Institute. This newer method, with certain modifications, was recommended for measuring the spin of plastic rotating bands at Picatinny Arsenal. Picatinny Arsenal has made further improvements and simplifications of this method.

71. As a result, Picatinny Arsenal now is in a position to measure the spin of projectiles more cheaply and more accurately than was previously possible. A detailed description of the instrumentation involved can be found in the Appendix.

72. In November 1955, bands made of Polyurethane U and of three different polyvinyl chloride compounds (Geon 8700a, Boltaron 6200, and Boltaron 7200) were test fired. Standard M74 projectiles with gilding metal bands were fired to warm the guns and for comparison. Seven bands made of phenolic fabric laminate were also included. Bands molded of Marlex 50 (high density polyethylene) and Cycolac (styrene terpolymer) were tested in June 1956. Two velocity levels were chosen, 2300 fps and 2600 fps with 40,000 psi and 50,000 psi pressures, respectively. Two width of bands were at first tested, 0.775 inch and 0.900 inch. Since results showed no significant difference, only one size, 0.800 inch, was used in the 1956

Fig 8 37 mm M74 Shot with Modified Band Seat and Geon 8700A Band, after Recovery in Sawdust tests. All firings were performed at ambient temperatures.

73. With the exception of the phenolic laminate and the polyethylene, all band materials gave good ballistic performance over the short range that was observable. With the same two exceptions, spin was in all cases close to 100% of the desired rate. Band retention was 100% for Cycolac and approximately 50-75% for the three PVC compounds. For polyurethane, band retention varied erratically, being 95% at 2300 fps and 30% at 2600 fps. The phenolic laminate bands apparently broke up within the barrel and the projectiles tumbled. The Marlex 50 bands performed satisfactory at 40,000 psi pressure, but at 50,000 psi the lands of the bands were almost completely worn off, insufficient spin was obtained, and the projectiles yawed.

74. The preliminary firing tests on the 37 mm scale indicate that several plastics--Cycolac, Polyurethane U, and the rigid polyvinylchlorides--can be considered promising as possible materials for rotating bands. The tests in which the heavy (solid steel) M74 AP projectile was fired at 40,000 and 50,000 psi pressure were severe, yet good ballistic performances were obtained throughout by all the materials tested. Additional tests at different temperatures and higher velocities are recommended.

75. Even the latest high density types of polyethylene are not suitable. Not only is marginal performance obtained at low velocities, but recent investigations of tensile properties at high rates of load application show only a minimal increase of strength with increased speed. Finally, the rather low heat distortion point indicates that performance would be poor at elevated temperatures. The laminated phenolic bands proved to be too brittle.

76. For the 70 rounds of which flight pictures were taken (Figs 9, 10, and 11, pp 29, 30 and 31), the retention or discarding of the bands could be definitely established. For the other rounds fired, band retention was determined, with a somewhat lesser degree of certainty, from the presence or absence of small holes in the yaw cards. If band retention should be made an absolute requirement, it will be advisable to take flight pictures of every round fired, until a material and a design which will give 100% retention has been established.

77. Considering that the band seats of the projectiles used in these tests had to be remachined after the gilding metal bands were removed, and were therefore not always perfect, the results are very encouraging.

PLASTIC ROTATING BANDS DEVELOPED AT SFAL FOR SPECIFIC END ITEMS

78. Development of an optimum plastic rotating band, as has been shown in the preceding chapters, has been a slow process. In the meantime, artillery ammunition design engineers demanded plastic bands for certain specific end items, where metal bands had given

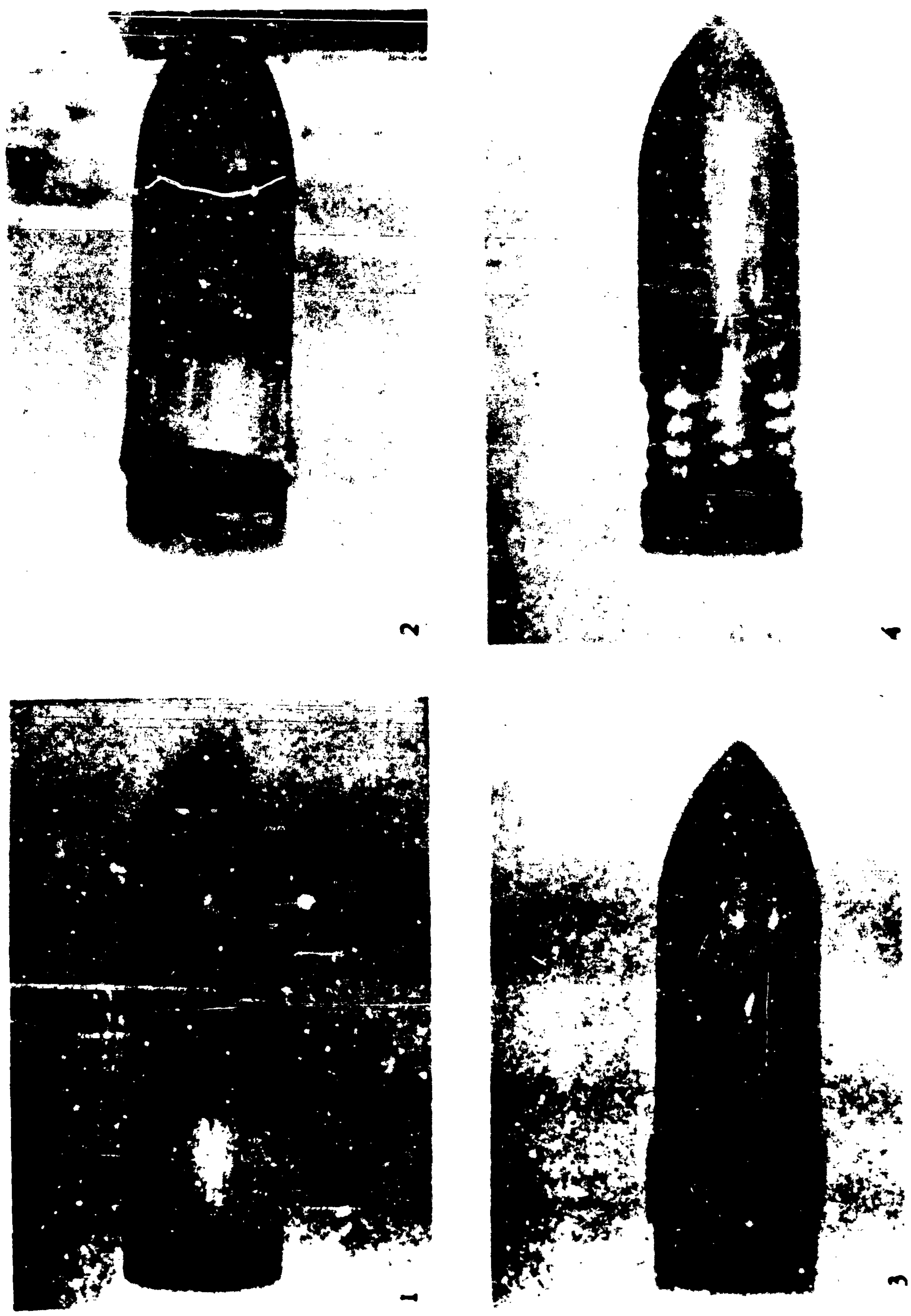

Fig 9 Plastic-Banded 37 mm M74 Shot in Flight: (1) Rd 112, Cycolac at 2612 fps; (2) Rd 122 Cycolac at 2632 fps; (3) Rd 124, Boltaron 7200 at 2593 fps; and Rd 126, Boltaron 7200 at 2632 fps (band discarded)

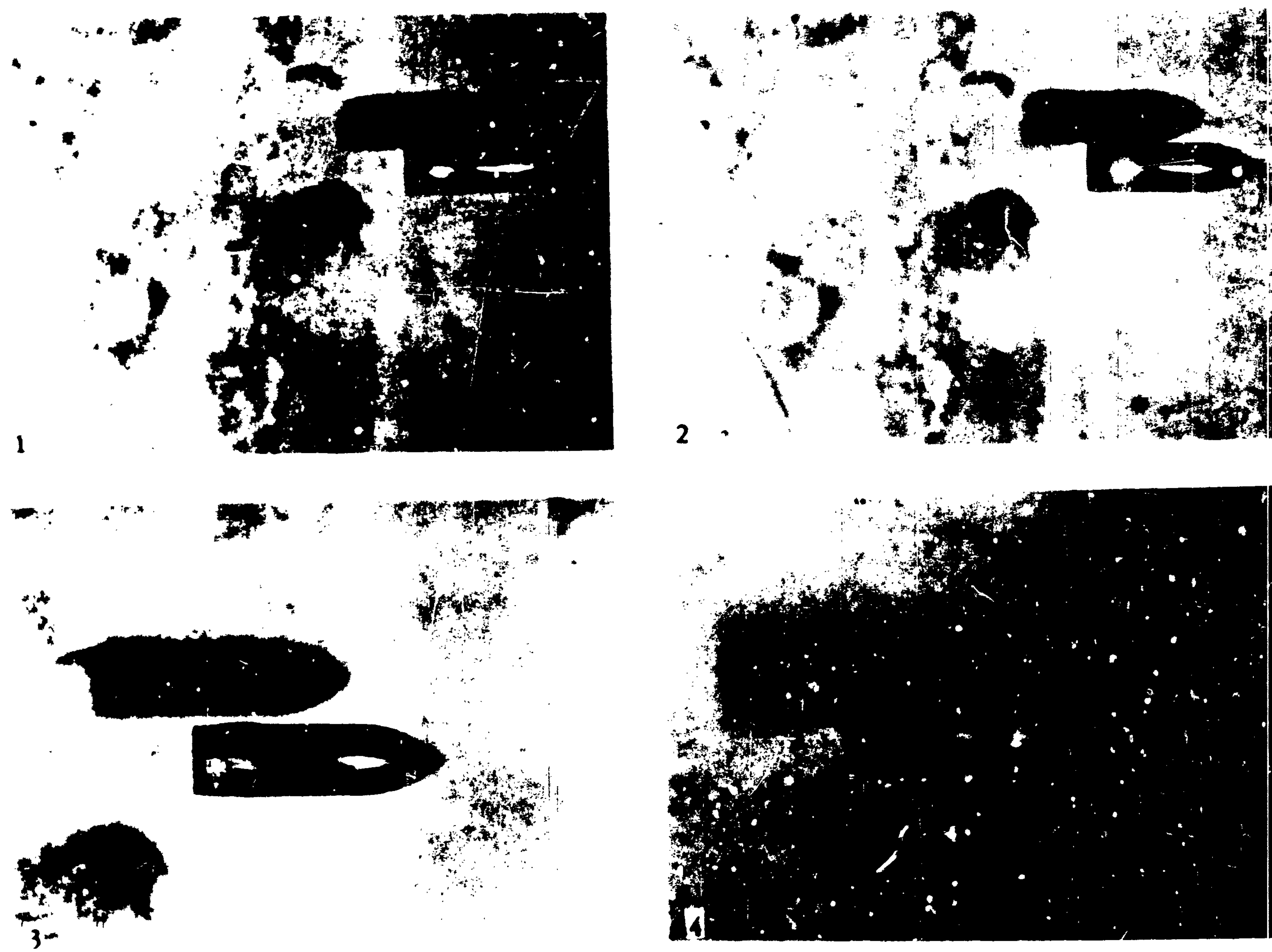

Fig 10 More 37 mm Flight Pictures: (1) Rd 22, Polyurethane U at 2596 fps; (2) Rd 36, Polyurethane U at 2315 fps; (3) Rd 74, Boltaron 6200 at 2591 fps; and (4) Rd 97, Boltaron 7200 at 2617 fps.

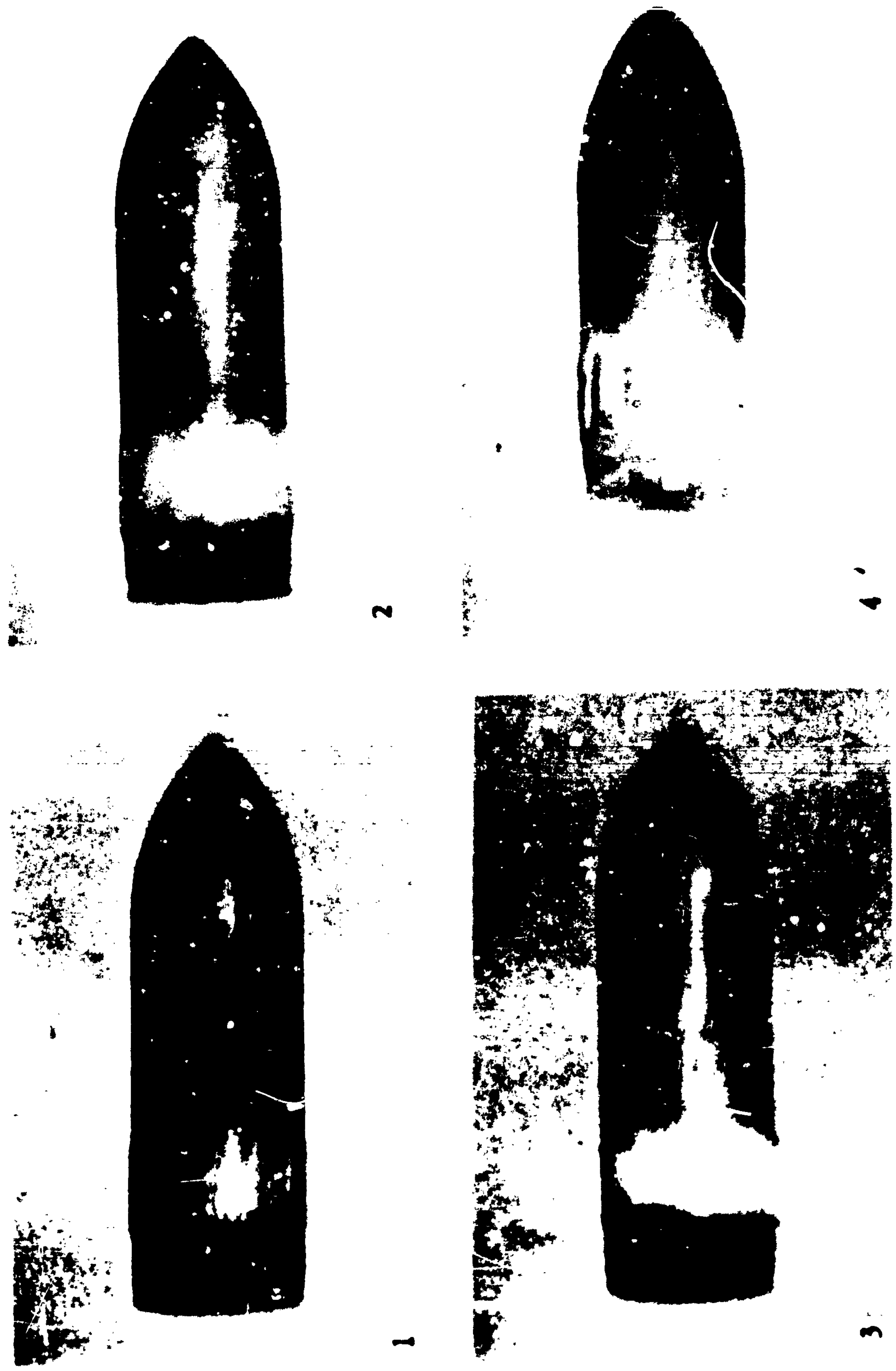

Fig 11 More in Flight Pictures: (1) Rd 139, Cycolac at 2365 fps; (2) Rd 150, Marlex 50 at 2365 fps; (3) Rd 138, Polyurethane I at 2574 fps; and (4) Standard gilding metal at 2518 fps.

TABLE 3

Average Results of Tests Firings of 37 MM M74 Projectiles with Plastic Rotating Bands Conducted during 1955 and 1956 at Picatinny Arsenal

	2300 fps Firings			2600 fps Firings		
	Spin %	Band Retention, %	Amount of Yaw	Spin, %	Band Retention, %	Amount of Yaw
Cycolac	100	100	None	100	100	None
Polyurethane U	100	95	None	100	30	None
Geon 8700 A	100	50	None	100	50	None
Boltaron 6200	100	75	None	100	75	None
Boltaron 7200	100	50	None	100	50	None
Marlex 50	100	100	None	60	10	Some
Phenolic Laminate	--	--	---	--	0	Some

unsatisfactory performance. Since no definite recommendations could be made at that time, development of bands for such end items frequently necessitated both materials and design studies. Brief descriptions of the problems encountered in applying plastic bands to particular projectiles are given below.

Shot, 76 mm T290 HVTP

79. This round is to be used for target practice purposes in place of high-priced HVAPDS M331 rounds with tungsten sub-projectiles. Low production cost, high velocity, accuracy, and small barrel wear are the prime requirements for this round. Since metal bands caused too much barrel wear, plastic bands were considered as a possibility.

80. The first bands were transfer-molded of Geon 8680, a Type I PVC. Substantial amounts of molded-in stresses were encountered, as approximately 40% of these bands developed cracks within a few weeks after molding. The first test firings, at APG on 12 May 1953, looked promising, however, at velocities of 4300 fps to 4400 fps, good flight characteristics were obtained and the probable error (PE) on a 1000-yard target was only .35 mils horizontal and .25 mils vertical. When the propellant charge was increased to obtain higher velocities, half of the rounds yawed.

81. A second lot of bands for this round was made of a Type III PVC, Geon 8700A. To avoid the molding difficulties that had been encountered with the first lot, the bands were machined from extruded pipe and mounted by the rubber-swaging-die method described in paragraph 60. When fired in Feb 1954 in the T91 gun with 40,000 psi pressure and 4,300 fps muzzle velocity a horizontal probable error (PE_H) of 0.31 and a

vertical probable error (PE_V) of 0.29 mils were obtained on a 1000-yard target. When these rounds were fired at 51,000 psi (112% of maximum rated pressure), velocities of over 4700 fps were reached with a PE_H of 0.47 mils and PE_V of 0.47 mils.

82. Shell with molded Geon 8700 bands and shell with molded nylon bands were fired on 17 and 18 May 1954 to compare their performance with that of shell having integral steel bands. No conclusions could be reached, however. The accuracy of the shell with plastic rotating bands was too poor because the gun barrel used had been badly worn by the metal-band firings.

83. Additional Geon 8700 and Exon 402 bands were molded and in November 1954, the tests were repeated with a new gun. No significant difference could be observed between the two plastic band materials. Accuracy was good at ambient temperature and pressure, and fair at high pressures (over 45,000 psi) and temperature extremes. All bands came off in firing, and it had to be concluded that the band seat used was inadequate for band retention.

84. The band seat design was improved, and additional bands were injection-molded of Geon 8700A by Tube Turns Plastics, Inc. In firings on 16 May 1955, bands with seat design PX-13-1810 (Figs 12, 13, and 14, pp 34, 35, and 36) were retained and gave better accuracy than all other designs fired. (PE_H 0.09, PE_V 0.27) Additional firing tests at extreme temperatures are planned.

90 mm T137 HVAPDS

85. Nylon 6.6 was chosen as the rotating band material for this round. Since the sabot of this round is made of magnesium, a material which is easily deformed, a screw-on band design was considered. The performance of this nylon band confirmed the experiences of other investigators. The performance was, in general, not consistent, and the accuracy dropped off rapidly when partly worn guns which still gave acceptable accuracy with metal bands were used.

86. The investigation of molding methods for this band is still going on, with the expectation that the inconsistencies in performance can be overcome by the development of a band material of more uniform properties. No means are known of sustaining the accuracy while wear in the gun barrel increases. The rate of barrel wear could be reduced, however, if it could be arranged to fire rounds with plastic bands exclusively.

105 mm T79E1 TP-T Shot

87. Originally, sintered iron bands were designed for this projectile. Erosion and wear of the barrel of the T140 gun was excessive when this type of band was used. Experiments are in progress at the present time to determine whether a nylon band would bring about a significant improvement.

120 mm T147E3 TP-T Shot

88. Test firings at Aberdeen Proving Ground of T116E5 and T147E3 shot

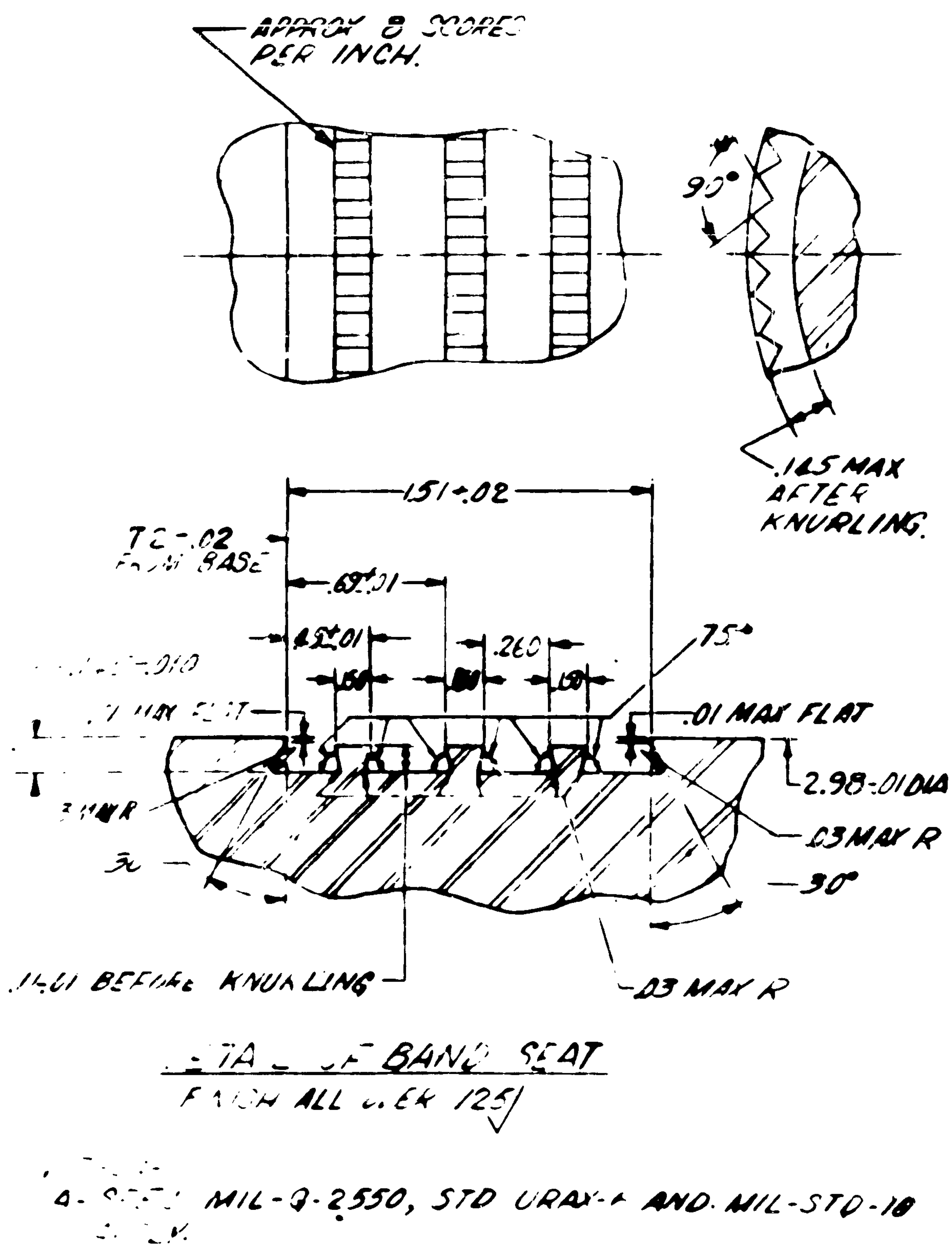

Fig 12 Rotating Band Seat for 76 mm Shot, Design Study No. 3. (From Drawing PX-13-1810).

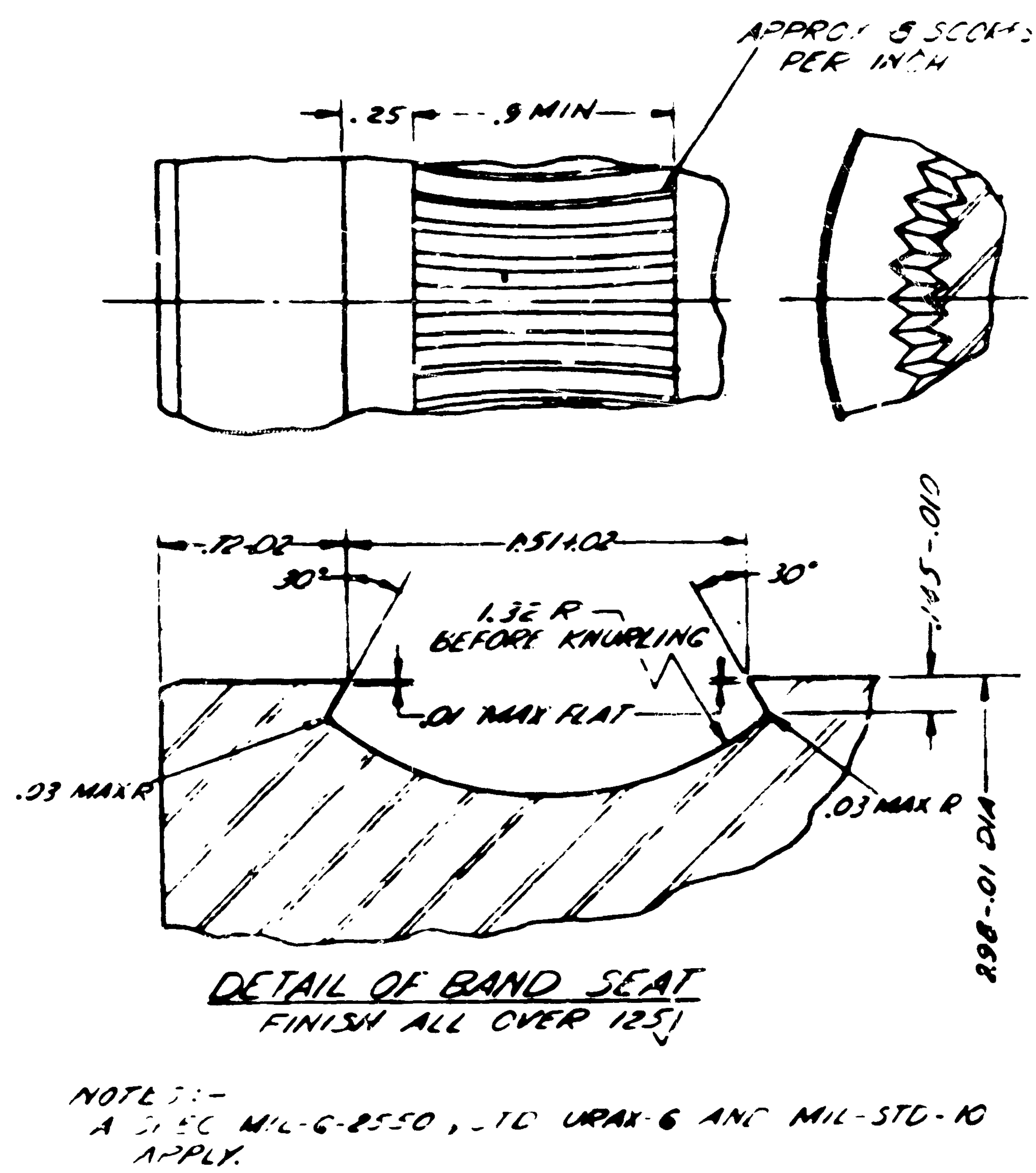

Fig 13 Rotating Band Seat for 76 mm Shot. Design Study No. 1. (From Drawing PX-13-1808).

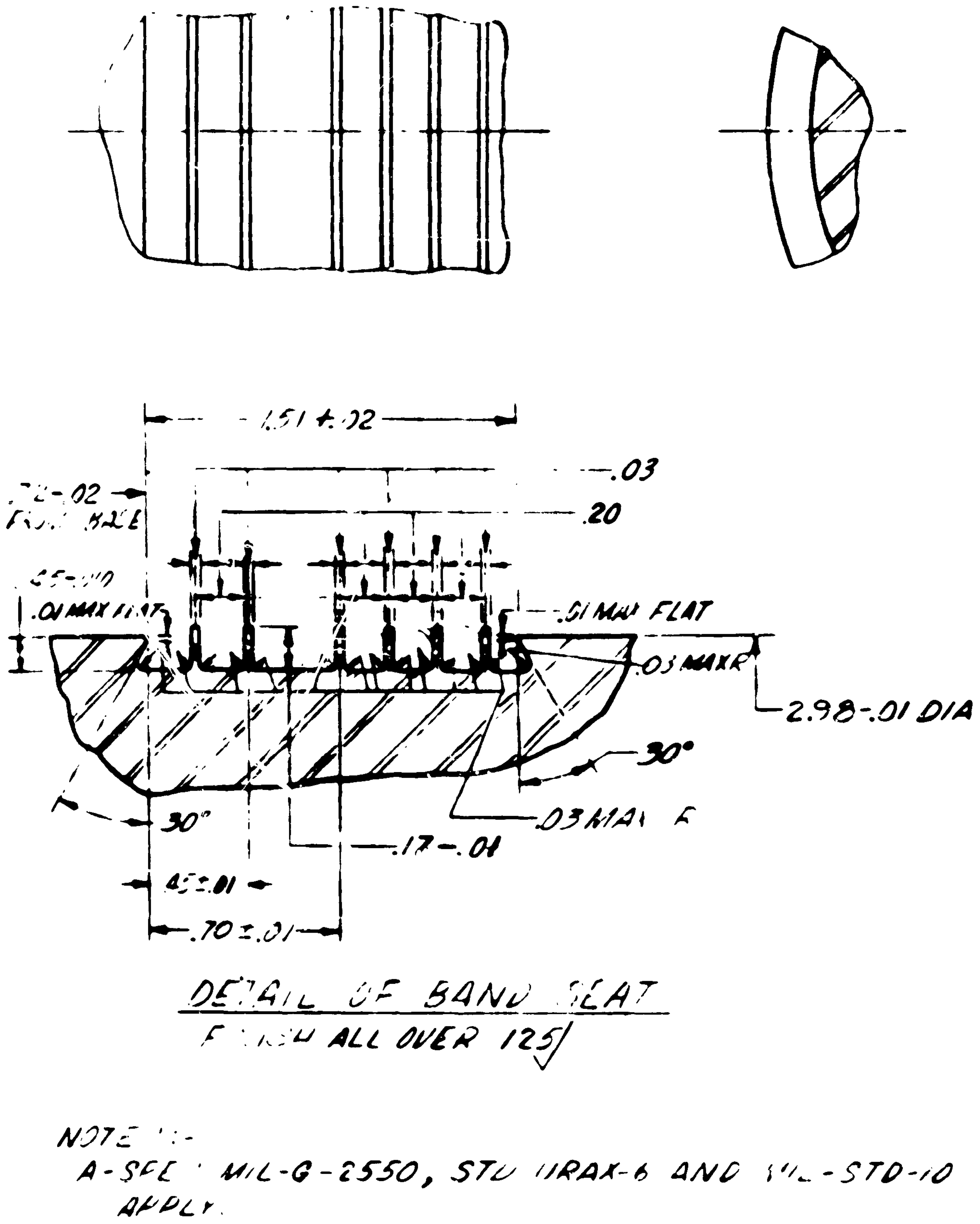

Fig 14 Rotating Band for 76 mm Shot, Design Study No. 2. (From Drawing PX-13-1809).

disclosed that the gilding metal bands were being sheared at various points around their circumferences. It was also disclosed that the shot were emerging from the gun engraved on the bourrelet and even on the body relief. The gun erosion associated with these firings was found to be excessive.

89. Since screw-on nylon bands had recently been used successfully on the 120 mm T102 HVAPDS-T shot, it was decided to modify a quantity of the T147 shot bodies to receive this type of plastic band.

90. Ten T147 rounds with screw-on nylon bands and rubber obturators were fired for accuracy in April 1956 with the following results:

PE_H	.09 mils
PE_V	.19 mils
Obturation	Fair
Pressure	38,000 psi
Velocity	3350 fps

When 8 additional rounds were fired for recovery, they were found to have no engraving of the shot body relief and only slight engraving of the forward bourrelet. Additional tests are planned.

90 mm HEAT Shell, T249E4 and E1

91. This round, as first designed by A.D. Little, had an ethyl cellulose rotating band. This band did not perform satisfactorily at low temperatures. Subsequently, PVC (Geon 8700 A) bands were provided by SFAL. Several test firings indicated perfect functioning of this band and good accuracy. Since this round is used in a shoulder-fired recoilless weapon, only low pressures and velocities of approximately 1000 fps are required. Rigid PVC is well suited for this application.

BIBLIOGRAPHY

British Reports

1 through 4. *Neoprene and Phenolic Bands (57 mm)*, Intelligence Reports R1537-47, R6218-47, R7302-47, and R7365-47.

These four reports cover discussions with Col G.O.C. Probert and other representatives of Armament Research Establishment, Ft. Halstead. Early experiments with bands made of neoprene-ebonite and phenolics are described. Projectiles with plastic rotating bands were test fired in the 17 Pr. (3 inch and the QF 6Pr 6 cwt (57 mm) guns. These bands had strength enough to impart proper spin, obturation was good; all bands were discarded near the muzzle. It was concluded that the discarding of the bands was conducive to improve exterior ballistics and increased range.

5. *Nylon and Its Use for Bands for Projectiles*, Ministry of Supply, Directorate of Weapon Research, WR (D) 6/52, IT 1098/52

This report concludes that nylon rotating bands cannot be recommended,

because shortages of nylon exist in England. Quantitative information on properties is lacking and no methods for non-destructive inspection of thick sections are available.

6 *Some Physical Properties of Molded Nylon (6.6) and Their Dependence on Conditioning and Aging Treatments,* Ministry of Supply, Chemical Inspectorate Report No. 63, ID 1138433

The results of mechanical tests on injection-molded tensile and impact specimens of nylon conditioned to various moisture contents up to saturation and then exposed to various levels of temperature (-60°F to +140°F) and humidity are recorded, together with observations on their dimensional, weight, and density changes; crystallinity; solution; viscosity; and corrosive effect on metals. The impact strength of water-treated nylon is much greater than that of dry nylon at ordinary temperatures and very much less at -60°F. Linear changes of about 2% and weight changes of about 7% are recorded for molded nylon which has been exposed under wet conditions for three months at 140°F (e.g., water-saturated nylon exposed under dry conditions and dry nylon exposed under wet conditions). The results indicate that the embrittlement occurring during the aging of nylon moldings is associated with the growth of crystallites and is apparently not due to chemical hydrolysis.

7. *Non-Metallic Driving Bands,* ARE Ballistics Branch Memorandum 5/52, ID 1091432, July 1952

This report describes the development of a discarding band for fixed ammunition. Trials indicated that it is possible to provide a discarding band in natural rubber ebonite which functions in single shot firings under temperature conditions regardless of the state of wear of the gun barrel, provided the gun design is suitable and the bore surface is not rough. The advantages of such bands are given as: low band pressure, increased range and gun life, satisfactory functioning at high velocities, and better maintenance of ballistics. The band fragments were found to constitute a danger area within a 20° semi-angle cone around the trajectory in the immediate neighborhood of the gun.

8. ARE Ballistic Branch Memorandum 84.

Describes the results of a study of gun wear.

9. *The Effect of Dry Heat on Water Saturated Polyaminde,* ARE Ballistics Branch Memorandum 93.

10. ARE Ballistics Branch Memorandum 96

Describes low temperature firing tests of plastic bands and sabots in Canada

11. ARE Ballistics Branch Memorandum 101.

Describes method of attachment of case over plastic rotating band.

12. ARE Ballistics Branch Memorandum 169.

Describes hard rubber rear driving cup on projectiles.

13. *A Review of the Problem of Providing Non-Metallic Materials for Use as Bands for Projectiles*, ARE Report of Non-Metallic Driving Band Panel.

14. *The Behavior of Driving Bands Made from Vulcanized Fiber of U.K. Manufacture*, ARE Ballistics Branch Memorandum 222, September 1953.

Reports tests of British vulcanized fiber. Rounds were found to have satisfactory performance.

15. *Vulcanized Driving Bands: Functioning of Simplified Designs*, ARE Ballistics Branch Memorandum 223, September 1953.

Various designs of bands were tested and it was found that spin was satisfactory in all instances although bands of some designs were retained and bands of others were not.

16. *Vulcanized Driving Bands: Functioning of Simplified Designs*, ARE Ballistics Branch Memorandum 225, September 1953.

Various additional designs were evaluated. Spin was satisfactory in all instances and apparently all bands were retained.

17. Functioning Trials of Non-Metallic Driving Bands—Improved Method of Projectile Recovery, ARE Ballistics Branch Memorandum 232, October 1953.

Several types of vulcanized fiber bands were tested. All functioning satisfactorily. A description is given of a new procedure, involving long range firing (several miles) followed by recovery in sand, which worked satisfactorily.

18. *Functional Trial of Experimental 40 mm Shot Banded with Fiber from the Anglo-American Fiber Co., Ltd*, ARE Ballistic Branch Memorandum 264, January 1954.

Additional tests with this particular British vulcanized fiber were made. It was found that spin was satisfactory and the bands were retained on all of the 12 rounds that were fired. It was concluded that this grade of vulcanized fiber is satisfactory.

19. *Behavior of Various Plastics as Driving Band Materials*, ARE Ballistics Branch Memorandum 265, January 1954.

Several materials were examined, also various methods of assembling the bands to the shell. The only material fired was phenol-formaldehyde/Hycar with asbestos filler. These rounds had satisfactory spin and were stable at the start of flight but all bands came off after the rounds left the gun.

20. *Behavior of Various Plastics as Driving Band Materials*, , ARE Ballistics Branch Memorandum 307, September 1954

Materials tested were: Ebonite A (natural rubber plus rubber dust), Ebonite B (natural rubber), Ebonite C (GRS), Ebonite E (GRS plus polyisobutylene), cast Araldite B, and phenol-formaldehyde/Hycar (approximately 84/16) with wound nylon cord. Spin was satisfactory in all cases and all rounds started with stable flight. In the case of the Ebonite indications are that many of the bands were lost during flight. In the case of Araldite it is definite that the bands came off. In the case of the phenol-formaldehyde/Hycar with nylon cord reinforcing material, spin was satisfactory although some yaw was observed. The bands were probably retained and engraving was fairly good. The results obtained with this last group are believed to be encouraging.

21. *An Appreciation on Nylon Driving Bands for 3" 70*, ADE D2 Technical Note 7/52, August 1952.

Attempts at a straight-forward substitution of nylon for copper proved impracticable. The adoption of a new ARE design is recommended.

22. *Report on Recent Developments on 3"/70 Stay-On Plastic Driving Band*, ADE D2 Technical Note 8/53, May 1953.

This report summarizes the limited success obtained with one ARE design and recommends further changes.

23. *The Use of Fromoplas H.T. as a Driving Band Material*, ADE D2 Technical Note 7/54, September 1954

This note reports recent trials with Fromoplas H.T. (modified polyvinyl formal) driving bands. Results indicate the possibility that, given correct chamber conditions, a screwed contoured band machined from blanks hot-pressed into a driving band groove with undercut knurls could be successfully developed.

24. *Materials for Non-Metallic Driving Bands. Part I. Foreword, and Part IIa. The Properties Required From a Driving Band Material*, Ministry of Supply, Directorate of Weapons Research WR(D) 3 53, ID 1176790, February 1953

In this report, the inadequacies of copper and gilding metal bands

are discussed. The necessity of finding non-metallic materials for rotating bands is stressed. For plastics, the collection of a large amount of basic data would be necessary before any serious attempts at the choice of materials could be made. The properties of a good rotating band material are listed.

25. *Materials for Non-Metallic Driving Bands. Part IIb. Assessment of the Suitability of Materials for Service Non-Metallic Driving Bands*, Ministry of Supply, Directorate of Weapons Research WR(D) 11/55, May 1955

Tests for evaluating materials in terms of their suitability for use as rotating bands are described. Functioning tests, storage tests, manufacturing aspects, and desirable physical properties are dealt with in great detail.

26. *Tropical Testing of QF 20 Pdr, APDS T Mark 3 Fitted with Nylon Driving Bands*, Tropical Testing Establishment (TTE) Report 304, 1st Interim Report

27. TTE Report 337, 2d Interim Report

28. TTE Report 364, 3d Interim Report

29. TTE Report 402, 4th Interim Report, 9 August 1954

30. TTE Report 427, 5th Interim Report, 28 April 1955

31. *Driving Bands for QF 20 Pdr APDS*, Proceedings of the Ordnance Board, 15 May 1956, Q8436

Because superior accuracy was obtained with vulcanized fiber bands, additional large scale tests of vulcanized fiber bands are planned.

32. *Travel Report*, Dr. Gilman, Chemical and Plastics Research Lab, SFAL, Picatinny Arsenal, 20 January 1955.

Reference is made to verbal information obtained from:

a. Col. J. Flowerdew of the Armament Design Establishment (ADE), Ft. Halstead, England

b. British Ministry of Supply (AD/MXRD and MX4) Shell Mex House, London, H. Warburton Hall, and G.A. Collie.

c. Armament Rsch Establ (ARE), Woolwich Arsenal, Col A.B. Robertson, L. Permutter, and J.H. Martin.

33. *Verbal Information* obtained by H.A. Tisch, SFAL (Picatinny Arsenal) from H. Warburton Hall of the British Ministry of Supply.

Franklin Institute Report

34. *Research & Development in Connection with Artillery Ammunition and Materiel*

to Obtain Data for use in the Design of Optimum Artillery Ammunition, Final Report 326, Contract W-36-034-ORD-6726, 1 July 1946 to 20 May 1947.

In this first report, preliminary studies of rotating bands, rifling, friction, time-travel, and other topics are discussed.

35. Interim Report I-1858, Contract W-36-C34-ORD-7663, 21 May 1947 to 30 September 1948.

The first plastics tested were: Teflon, Nylon 6.6, vulcanized fiber, lignin resin, and vinylite. Methods of band application used were: cementing base cup bands to base; Slipping band on hot and letting it shrink; conventional method of pressing the band blank (hot or cold) into the band seat by means of a West hydraulic banding (tire setting) machine; injection or compression molding of the band directly to the projectile; and forcing the band over a knurled conical surface on the projectile.

Because it was too weak, Teflon gave consistently poor results in these .50 caliber firing tests. Vulcanized fiber gave the best results, especially in erosion firings where its performance surpassed all other rotating band materials tested. Fair results were obtained with molded vinylite bands. All bands tested discarded.

Projectile spin was measured by recording the voltage generated in a pick-up coil as the rotating field of a transversely magnetized projectile passes through the coil, a method introduced by the British and further developed at Franklin Institute.

36. *Research and Development to Improve Artillery Ammunition and Material,* Final Report F-1996, Contract W-36-034-ORD-7663, 21 May 1947 to 7 November 1949

Plastic 20 mm prototypes of the bands to be used in the development of the 75 mm recoilless rifle projectile were fired successfully. They performed well at both low and moderate muzzle velocities. On the basis of these test results, two plastics from a group of ten were selected to be banded on 75 mm projectiles of this design.

37. Progress Reports P-2143-3, -6, -9, -10, -11, and Final Report F-2143-12, Contract DA-36-034-ORD-4, V 8 November 1949 to 15 October 1950.

Much effort was devoted to the evaluation and testing of moldable plastic materials for use in rotating bands. The excellent performance of several plastics in static engraving, dynamic engraving, and firing tests on a 20 mm scale demonstrated their general suitability for rotating band use.

Bands of ethyl cellulose were designed for 75 mm and 105 mm recoilless rifle projectiles. In test firings at Aberdeen Proving Ground at temperatures of −65°F, 70°F, and 165°F, the 75 mm bands performed with good accuracy. In the 105 mm tests, there was no damage to the thin-walled rifle barrel from the pressure of the plastic bands.

38. Final Report F-2214, Contract DA-36-034-ORD-63, 17 November 1950 to 15 December 1951.

Several new plastic materials were evaluated as rotating bands by dynamic engraving and firing tests on the 20 mm scale. A total of eighteen plastics had now been evaluated by such tests. Nylon FM 10001 is the only material that performed well at all temperatures and at both low (1100 fps) and high (2700 fps) velocities. Several other materials gave acceptable results under certain conditions and appear suitable for certain specific applications.

A brief study of the microstructure of ethyl cellulose bands before and after firing was made with the aid of an electron microscope. No significant change in structure as a result of firing was observed.

The investigation of the use of plastic bands in recoilless rifles was continued. The conclusion was reached that unengraved bands made of the plastics so far tested are suitable for use only in future rifles having certain special design features. Cal .50 erosion tests of nylon and ethyl cellulose bands showed much less barrel wear than any band, including iron wire, previously tested.

A preliminary investigation of certain band design factors was started. The effects of variations of band width, band diameter, seat diameter, and velocity were studied.

39. Final Report F-2287, Contract DA-36-ORD-690-RD, 16 December 1951 to 30 January 1953.

The performance of fifteen new plastics was evaluated by 20 mm firing tests. Fastening methods other than molding were studied. The results in several cases were most encouraging. In particular, two types of swaged Geon bands performed well at the high velocity level.

High temperature tests indicated that nylon may be acceptable as a substitute band material for

20 mm machine gun ammunition. A firing program to confirm this possibility was planned. A preliminary lot of 105 mm plastic bands was fired at Jefferson Proving Ground. Although the plastic bands were a direct substitution for the present gilding metal band with no changes in band dimensions, two nylon formulations performed quite well.

A plastic band was designed for a new 57 mm recoilless rifle. Since no service components were involved, both the tube and shell were modified to accommodate an optimum band. A firing test program for this band was prepared.

Since plastics have a much higher thermal coefficient of expansion than metals, equations were developed to predict band diameter at extreme temperatures. The equations were verified experimentally and will be a valuable aid in band design.

A system of instrumentation was developed to measure spin of 20 mm projectiles during flight. Statistical analysis of test results indicated that this instrumentation has a precision of ± 4% at the 95% confidence level. The system can be built for use with other calibers from the information given in the report.

40. *A Survey of Plastics for Rotating Bands*, Interim Report I-2358-1, Contract DA-36-034-ORD-1215 RD, 30 April 1954.

This report is a survey covering more than 40 moldable plastics. Their suitability for use as rotating bands was judged chiefly by their ability, when fired, to impart spin to a projectile, to obturate, and to be retained on the projectile in flight. The different materials are described, also the manner of making and fastening the bands and the way in which the bands were tested. Detailed results of tests in which they were fired under various conditions are given. The report also contains brief discussions of fastening methods other than molding, gun erosion, design parameters, and engraving characteristics. The conclusion is reached that plastics are generally suitable for use as rotating band materials. Several moldable plastics are designated as most promising.

41. *A General Discussion of Rotating Band Design*, Interim Report I-2358-4, Contract DA-36-034-ORD-1215 RD, 23 May 1955.

This report summarizes and evaluates presently available band design methods. The functions and features of a rotating band are explained. The many new materials (soft iron, sintered iron, nonferrous alloys, and plastics) which a designer can use now are discussed in terms of these basic junctions and features. A simple band design problem is worked out in detail, and suggestions are given for making firing tests of new bands. In general, the report reveals the inadequacy of our present methods for designing and testing rotating bands.

42. *Preliminary Development of Plastic Rotating Bands for the 27 mm T142 Practice Projectile,* Interim Report I-2358-5, Contract DA-36-034-ORD-1215 RD, 23 May 1955.

This report contains the results of a preliminary study of nylon rotating bands for the 27 mm T142 practice projectile. Four bands designs were developed, one for direct substitution for gilding metal, one for maximum driving edge bearing stress, one for maximum shear stress, and one for greater interference than gilding metal. These band designs were subjected to preliminary firing tests results of which may be summarized as follows:

a. Two of the four designs (representing maximum bearing stress and maximum shear stress) imparted full spin to the projectiles.

b. All bands separated from the projectiles because of extreme test conditions and inadequate band seat designs.

c. Recovered bands showed that the values chosen for bearing and shear stresses are safe for nylon. It was concluded that nylon rotating bands meet the rotational requirements, but that further experimentation will be needed to solve the problem of band retention.

43. *Firing Tests of Plastic Rotating Bands for 57 mm Recoilless Rifle,* Interim Report I-2358-7, Contract DA-36-934-ORD-1215 RD, 23 May 1955.

During the past few years, an extensive development program on the 57 mm recoilless rifle has been conducted. The aim of the program has been to reduce the weight of the weapon and to investigate the feasibility of using unengraved plastic rotating bands. This report contains the results of a proof test of nylon and ethyl cellulose bands. Franklin Institute designed the bands and modified an experimental tube for the firing test, which was conducted on a Frankford Arsenal range.

The test results showed that both nylon and ethyl cellulose bands give projectile performance comparable to that provided by pre-engraved bands. The proof test also demonstrated that the band design was not optimum with regard to band pressure and band retention. The band separation multiple bands and a redesigned band seat.

44. *Plastic Flow of Rotating Bands during Static Engraving*, Interim Report I-2358-9, Contract DA-36-034-ORD-1215 Ra, 23 May 1955.

A method is proposed for calculating the engraving resistance of a rotating band. Grid-works are inscribed on the rotating bands and a quasi-static, step-wise engraving process is used to obtain data on the incremental strains in the bands. It is postulated that combining these strains into an octahedral shear strain pattern will give the same parameter in actual firing as in static testing. It is further postualted that, if the strain rates for the increments are known, the proper stress-strain curve will indicate the band stresses. From these stresses, the engraving resistance can be derived.

A special camera is described which measures band displacement accurately by taking enlarged photographs. A mathematical derivation is given for a new method of finding surface strains from gridwork motions. This engraving experiment was performed on 96 - 20 mm projectiles with gridworks inscribed on their bands.

45. Final Report F-2358, Contract DA-36-034-ORD-1215 RD, January 1953 to May 1955.

This report restates in condensed form the findings published in Interim Reports 2358-1 to -9. In addition, results of erosion firing of cal .49 projectiles with glass fiber-filled polystyrene bands are reported. It was concluded that gun tube wear from these bands is not excessive and may be even slightly less than that produced by nylon, the least erosive band material tested thus far.

Existing methods of band design were summarized and evaluated, and the characteristics of band materials now available were reviewed. In general, this work reveals the inadequacy of present design procedures. Several ways of improving design criteria are suggested.

A study was begun of the mechanisms by which the driving edge of a band-land fails to support the rotational force applied by the rifling. An experimental set-up was developed to the point where the loading and resultant displacement of the driving edge could be determined satisfactorily.

46. Minutes of Conference on Rotating Bands held at Watertown Arsenal Laboratories 19-20 February 1951, published by Franklin Institute. (Confidential)

Naval Ordnance Laboratory (NOL) Reports

47. S.P. Prosen and J.J. Strobel, *The Development of 3"/70 Rotating Bands and Sealing Cups,* NAVORD 2308, 13 March 1952.

Development of designs and molding methods for plastic rotating bands. Nylon and ethyl cellulose were used as band materials.

48. J.E. Long and S.P. Prosen, *Investigation of the Use of Plastic Rotating Bands on 20 mm Projectiles. Progress Report I,* NAVORD 3716, 20 May 1954.

Ten types of plastics were investigated as bands for 20 mm projectiles fired from a standard 20 mm barrel. A qualitative analysis of the test results showed that two injection-molded nylon materials and one epoxy-type casting material had performed satisfactorily as 20 mm rotating bands at velocities up to 3350 fps.

49. S.P. Prosen, *Accelerated Aging of Molded Nylon and 20 mm Nylon Rotating Bands,* NAVORD 3931, 28 March 1955.

Injection-molded test specimens made of Nylon FM 10001 (Zytel 101) exposed to storage conditions of 150°F and 100% R.H. showed a severe degradation of physical properties after one week of exposure. However, 20 mm rotating bands molded from the same batch of Zytel 101 performed satisfactorily in −65°F, ambient, and 160°F firings after 10 weeks of the same exposure. The band diameters expanded as much as 0.010" during exposure. The advantages of cooling the nylon bands quickly after molding are described.

50. S.P. Prosen and T.J. Williams, *Investigation of the Use of Plastic Rotating Bands on 20 mm Projectiles. Progress Report II,* NAVORD 3909, 9 May 1955

Plastics of three types were [illegible] continuation of [illegible] program to develop plastic rotating bands for 20 mm projectiles. One molded nylon (Zytel 101) and one molded PVC material (Geon 8700A) performed satisfactorily as rotating bands for 20 mm projectiles up to maximum obtainable velocities of approximately 4000 fps.

51. T.J. Williams and S.P. Prosen, *Investigation of the Use of Plastic Rotating Bands on 20 mm Projectiles. Progress Report III,* NAVORD 4134, 28 September 1955.

Seven types of plastics were investigated in connection with the 20 mm plastic rotating band program. Three of the seven types tested (Cycolac 12830, Nylon BN-3, Geon 81141) performed satisfactorily as rotating bands for 20 mm projectiles up to maximum obtainable velocities of approximately 4000 fps.

Naval Proving Ground Reports

52. R.B. Butler, *Rotating Band Study,* NPG 658, 13 October 1950.

53. R.B. Butler and D.L. Winchell, *Design and Tests of High Velocity Nylon-Banded Projectiles,* NPG 720, 23 January 1951.

A nylon band was developed for ammunition for the 3"/50 gun which functioned successfully in new guns at muzzle velocities up to 3050 fps, imparting full spin and obturating satisfactorily. All bands tested discarded at or very near the muzzle as small pieces. Further improvement is needed.

54. R.H. Lyddame, R.B. Butler, and D.A. Dickson, *Life Test of 3"/50 AA Gun Mk 22 Mod 5 with Nylon Banded Projectiles,* NPG 981, 10 June 1952.

The life of a 3"/50 Mk 22, Mod 5 gun, fired with NH powder, and in rapid fire, is approximately 1000 rounds when nylon-banded projectiles are used, as compared with approximately 450 rounds when copper-banded projectiles are used. The criterion of end of gun life for nylon-banded projectiles is loss of range accuracy for a fraction of the rounds. The substitution of nylon for copper reduces the rate of gun wear at the origin by a factor of approximately 5. The rate of wear forward of the origin is reduced by an even larger factor. Wild rounds probably occur because the process of engraving the band is affected by origin wear, even though the amount of wear would not be considered large for copper bands.

55. R.H. Lyddame and R.B. Butler, *Nylon Rotating Band for 20 mm High Velocity Projectile,* NPG 1099, 28 February 1953.

Nylon rotating bands were developed which imparted full spin to the projectile, obturated satisfactorily, and did not fringe or produce yaw to an unacceptable extent when tested in a 20 mm Mk 12 gun at muzzle velocities up to 3500 fps and at temperatures ranges from −65°F to +160°F. These bands appear, on the basis of a relatively small amount of firing, to be retained in flight.

56. R.B. Butler and F.P. DeGaetano, *Ballistic Test of 5"/3.75" Spin-Stabilized Discarding Sabot Projectile*

(with Nylon Rotating Band), NPG 1294, 24 September 1954.

57. R.B. Butler and F.P. DeGaetano, *Development of 5"/3.75" Spin-Stabilized Discarding Sabot Projectile (with Nylon Rotating Band)*, NPG 1300, 25 October 1954.

This phase of Naval sabot development work showed that an aluminum sabot base with a nylon rotating band will perform satisfactorily, giving a velocity of about 4200 fps at a pressure of 34,000 psi.

58. R.B. Butler and F.P. DeGaetano, *Development and Evaluation of a 5"/3.75" Spin-Stabilized Discarding Sabot Projectile*, NPG 1310, 26 November 1954.

With the Type 1 Mod 6 projectile described in this report a successful sabot design for both the 5"/54 gun and the 5"/38 gun was achieved. Excellent uniformity of velocity, pressure, sabot separation, and range was attained.

59. R.B. Butler, *Development and Test of Nylon Rotating Band for 20 mm High Velocity Projectile*, NPG 1342, 10 March 1955.

This report continues the account of the development work on nylon rotating bands previously reported in NPG Report 720. Extreme temperature firings indicated that a band seat design and a method of molding had been achieved which produces a band that is retained in flight under all firing conditions. Rapid fire results showed that satisfactory performance of the band is obtained even in a very hot gun. In chromium-plated barrels, the nylon bands produced a spectacular increase of gun life. The short range dispersion obtained in rapid fire was generally comparable with that obtained with gilding metal bands. In accuracy firing (slow fire) acceptable dispersion at long range was obtained.

60. R.B. Butler, *Development of Nylon Rotating Bands: Artificial Aging Tests*, NPG 1357, 25 Maryh 1955.

The nylon band developed for the 20 mm high performance Mk 12 aircraft gun which had previously shown excellent performance was subjected to artificial aging followed by firing tests to obtain information on the storage life to be expected of it. The artificial aging was conducted at temperatures of 150°F and 160°F and at 95% to 100% relative humidity for periods of up to 16 weeks. The results tend to indicate that the storage life of this band under service conditions will be adequate.

Mold temperature tests indicated that superior performance can be

obtained from nylon (Zytel 101) bands if the bands are produced in cool molds.

Limited tests of injection-molded PVC bands (EXON 402 and Geon 8700A) in the Mk 12 gun showed satisfactory ballistic performance with regard to projectile spin and band retention.

61. R.B. Butler and F.P. DeGaetano, *Ballistic Tests of 60-lb 5"/54 H.C. Projectiles with Various Band Materials,* NPG 1410, 17 October 1955.

In an attempt to obtain a rotating band for the 60-lb 5"/54 projectile which would show improved performance at high velocity, several band designs were subjected to limited testing.

As a result of these tests, it was concluded that:

a. An auxiliary welded overlay iron band added behind the standard gilding metal band decreased band wear in both new and worn guns and prevented projectile body engraving. In worn guns, the range performance was improved by the use of such auxiliary bands. The effect of the added iron band on gun wear in general is not known.

b. Swaged ingot iron bands, replacing gilding metal completely, show excellent engraving in new guns. In severely worn guns without spiral wear, such bands will fail. By the use of multiple cannelures, the maximum body deformation can be reduced substantially. The smallest amount of body deformation observed in 5"/54 tests to date, 0.017 inch, was obtained in this way. The range performance and the rate of gun wear with swaged iron bands remain to be determined.

c. With a given powder charge, any given velocity can be obtained with nylon bands at pressures which are from 4 to 6 tons lower than those for the gilding metal bands. By taking advantage of this pressure differential, a 60-lb projectile with nylon bands can be fired at velocities as high as 3286 fps without exceeding the 48000 psi service pressure limitation. In a new gun, at extreme velocity with the 60-lb projectile and at proof pressure with the 70-lb projectile, no band wear occurs. On the basis of the negligible wear of chrome-plated barrels in other calibers, nylon-banded projectile fired at high velocity in the 5"/54 gun should give acceptable gun life with low velocity loss.

Picatinny Arsenal Reports

62. Minutes of Symposium on Plastic Rotating Bands Held at Picatinny Arsenal 24-25 February 1954, Published by Picatinny Arsenal (Confidential)

63. Henry A. Tisch, *Mechanical Properties of Rigid Plastics at Low Temperatures,* Picatinny Arsenal Technical Report 1898, May 1954.

64. Henry A. Tisch, *Properties of Rigid Polyurethane,* Picatinny Arsenal Technical Report 2335, September 1956.

65. Henry A. Tisch, *Properties of Rigid Polyvinyl Chloride,* Picatinny Arsenal Technical Report 2382, November 1956.

66. Henry A. Tisch, *Swaging of Plastic Rotating Bands by Means of a Rubber Die,* Picatinny Arsenal Plastics Research Laboratory Report 53-M2-100, 30 December 1953.

A method of firmly seating plastic rotating bands made of extruded polyvinyl chloride tubing was established. A specially designed rubber swaging die was used.

67. E. Castagna, *Fabrication of Plastic Rotating Bands for 20 mm Projectiles,* Picatinny Arsenal Plastics Research Laboratory Report 54-M2-21, 26 February 1954.

This report shows that rotating bands can readily be fabricated by conventional molding methods and that they can also be made by casting, laminating, and swaging. The different methods, molds, and molding conditions for various thermoplastic and thermosetting materials are described.

68. Robert Barrett, *Resistance of Plastics to Outdoor Exposure,* Picatinny Arsenal Technical Report 2102, February 1955. (Confidential)

69. *Investigation of Method of Assembly of Complete Rounds Through the Medium of Rubber Dies,* Picatinny Arsenal Industrial Division Report 3, Problem P-46-9, 4 May 1953.

APPENDIX

Magnetic Method for Measuring Projectile Spin

The method used for measuring velocity and spin is a modification of the method used by the Franklin Institute. A shell is magnetized transversely and longitudinally, and fired through 2 solenoids connected in series with a pick-up coil. The magnetized projectile induces a voltage in the coils, which is of the same frequency as the spin. By measuring the period of this voltage the spin rate can be found. A description of the method follows:

Magnetization of Projectile

1. For cross magnetization of the projectile a jig (Fig 15) designed by the Instrumentation Section at Picatinny Arsenal is used. This jig is made up of approximately 210 turns of plastic coated No. 12 AWG Wire, wound on 1 in. steel stock. A 6-volt storage battery is used as a source of magnetomotive force. The jig has movable pole pieces to adjust the angle of magnetization.

Translational Velocity and Spin

2. Two marker coils and a pick-up coil

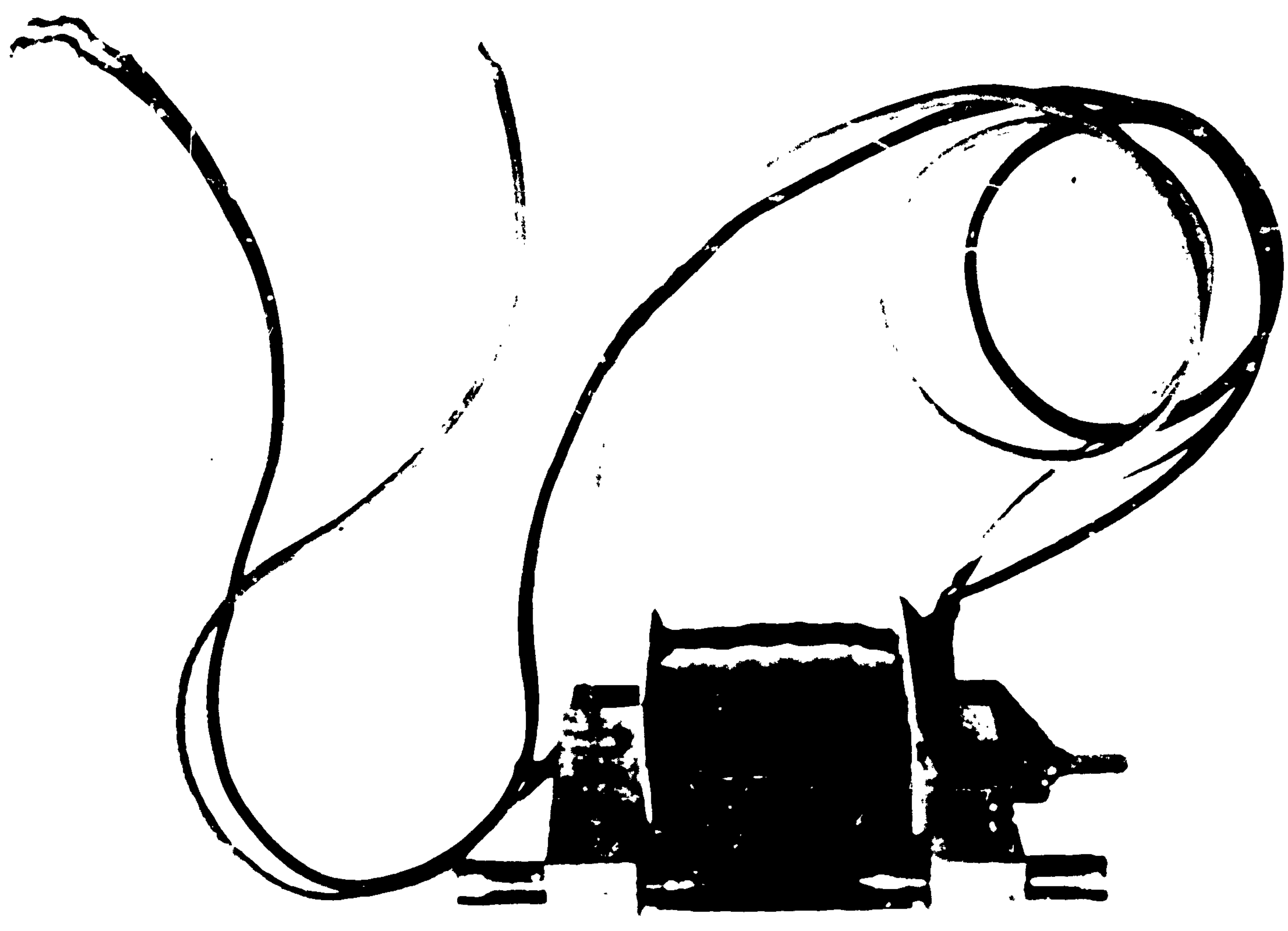

Fig 15 Magnetizer for 37 mm Projectile

(in this test coil lengths of 15, 25, and 35 feet were used) made up of 8 conductor cables are connected in series and physically located parallel to the trajectory as shown in Figure 16 (p 55). The two marker coils (about 24 inches in diameter) are securely fastened to wooden rings and suspended on a taut rope. The instrumentation used is shown in Figure 17 (p 56). The voltage induced in the coils by the moving projectile is fed into a Potter Instrument Shaping Adapter Model 661. This instrument has the features of an amplifier and pulse shaper; however, in these tests only the amplifier stage is used, the main purpose being to remove sixty cycle pick-up. The signal from the Shaping Adapter is applied to an Electronic Tube Corporation Type H4GEL Oscilloscope. An Electronic Tube Corporation Type Signal Generator Model ES1 provides a time base for the oscilloscope. (In these tests a frequency of 1042 cps was used). A drum camera is used for sequencing the recording and firing equipment, and for photographing the oscilloscope display. Figure 18 (p 57) shows the drum camera and oscilloscope; Figure 19 (p 58) shows sequencing roller and commutating contacts on the drum camera; and Figure 20 (p 59) shows sequencing chassis and Western Electric Type 275 relays used for switching. Only a portion of the sequencing units of this equipment were used in these tests. For a description of the construction and operation of this firing and sequencing equipment, see PA Tech Rpt No. 1818, subject: "Instrumentation for Obtaining Pressure and Thrust Data from Statically Fired Rockets and JATOS employing Propellant Powders as Fuel" prepared by G.F. Gensheimer.

Referring to Figure 21 (p 60) which is a typical trace, the following method was used to calculate the data on spin:

d = Distance between marker coils on trace in inches

D = Actual distance between marker loops in feet

N = Number of turns chosen for measurement

T = Time base in milliseconds of the distance d on trace

t = Time base in milliseconds of N turns on trace

S = Nominal twist (as specified by the manufacturer) of the 37 mm gun in feet per turn

The linear velocity of the shell in feet per second =

$$\frac{D \times 12 \times 10^3}{d \times T}$$

The rotational velocity of the shell in revolutions per second =

$$\frac{N \times 10^3}{t},$$

Theoretical spin in revolutions per second =

$$\frac{D \times 12 \times 10^3}{d \times T \times S}$$

$$\% \text{ Spin} = \frac{\text{Rotational Velocity}}{\text{Theoretical Spin}} =$$

$$\frac{N \times d \times T \times S \times 100}{t \times D \times 12}$$

The results of these tests indicate that the magnetic coupling system for the measurement of spin yield satisfactory traces. The Franklin Institute used a Tektronix oscilloscope in place of the 4-channel oscilloscope and a Polaroid camera in place of the drum camera used in these tests. The advantage of using a 4-beam oscilloscope lies in the fact that no lock out sweep circuit is necessary, as is required with the Tektronix oscilloscope to eliminate multiple sweeping. The substitution of the drum camera for the Polaroid camera is desirable because the associated firing and sequence units of the former provide automatic control of recording, and the traces are magnified approximately 6 times.

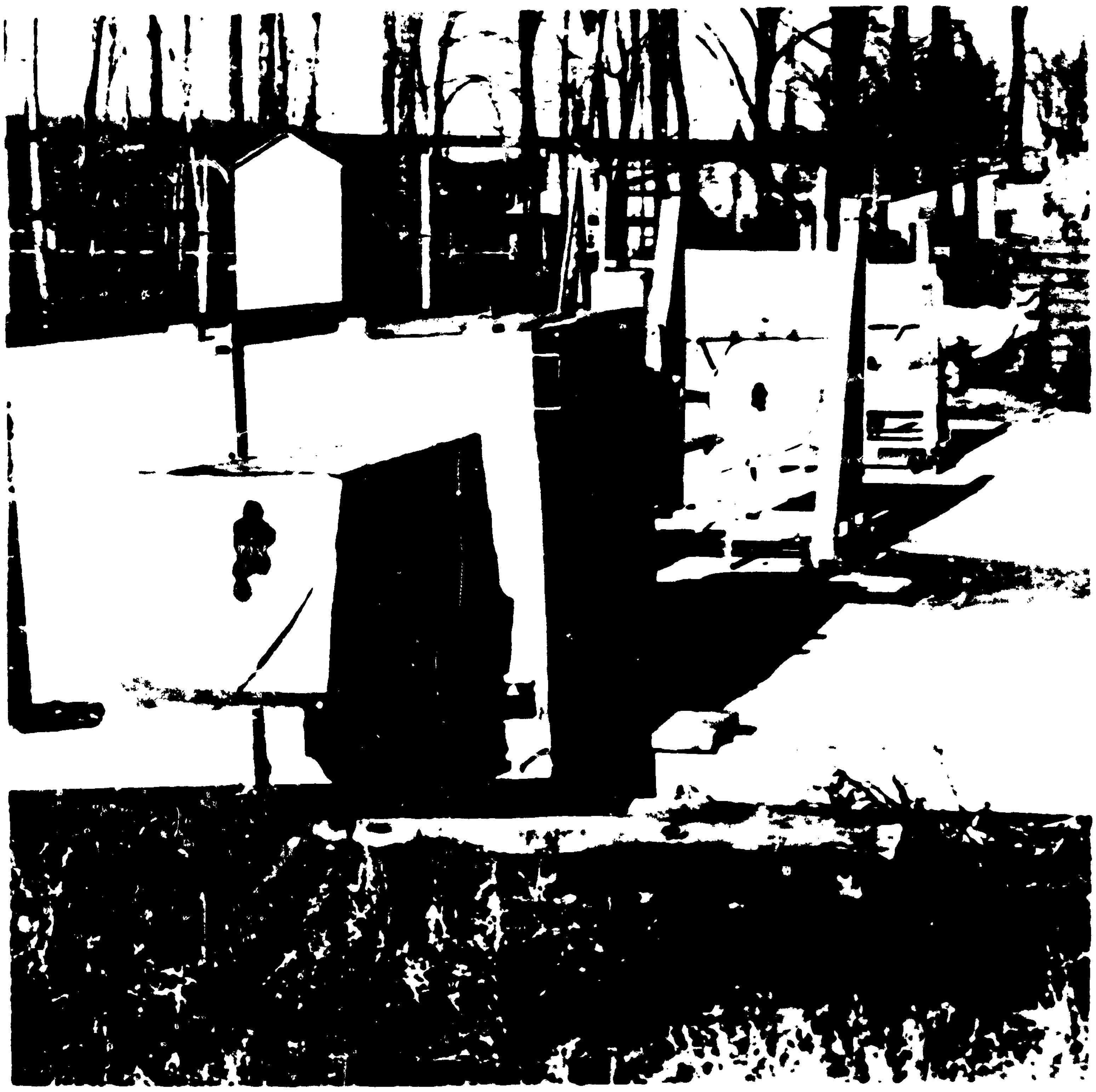

Fig 16 Picatinny Test Firing Setup. Flight picture box in foreground, spin measurement coils in background.

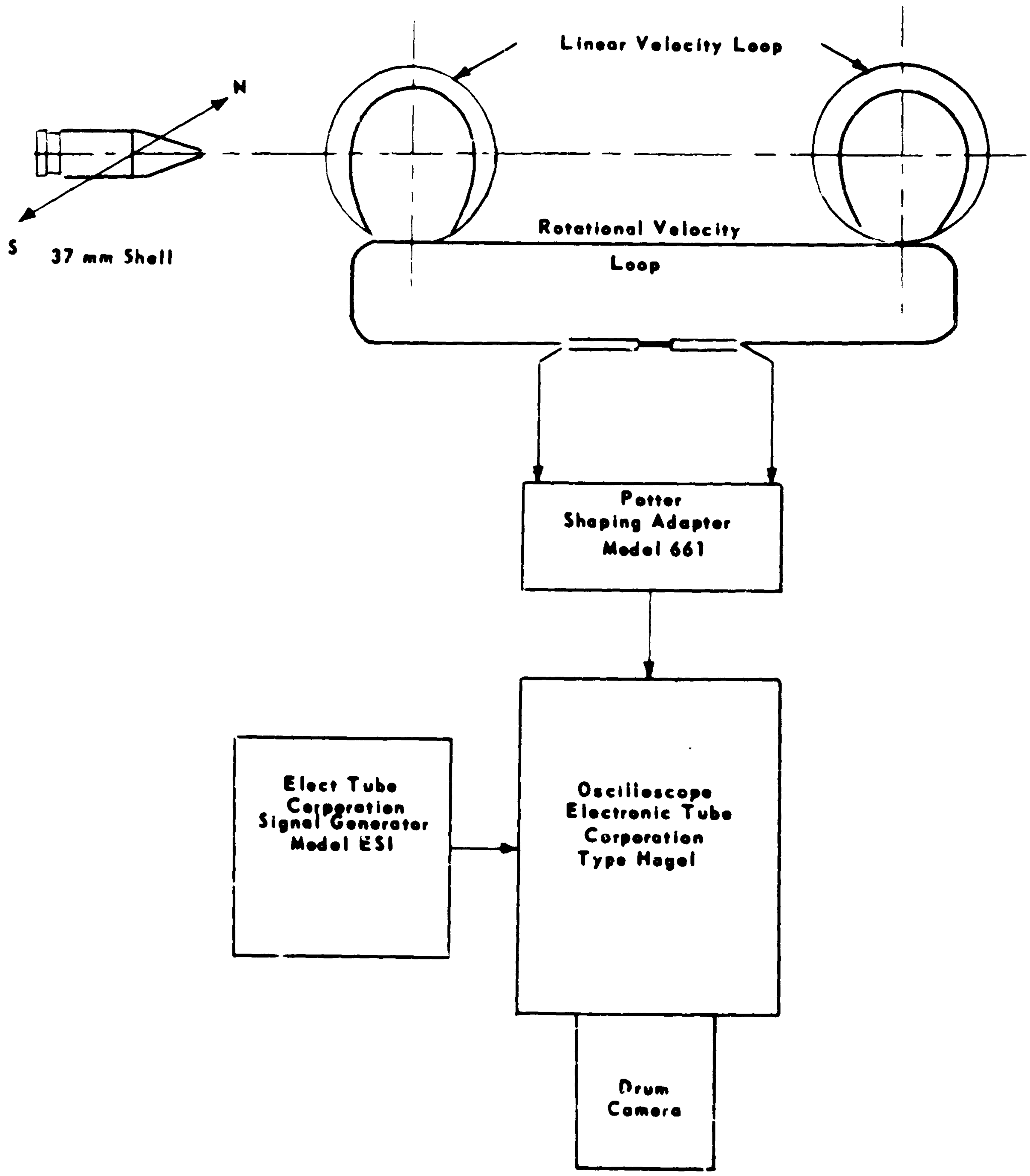

Fig 17 Instrumentation for Spin Measurement

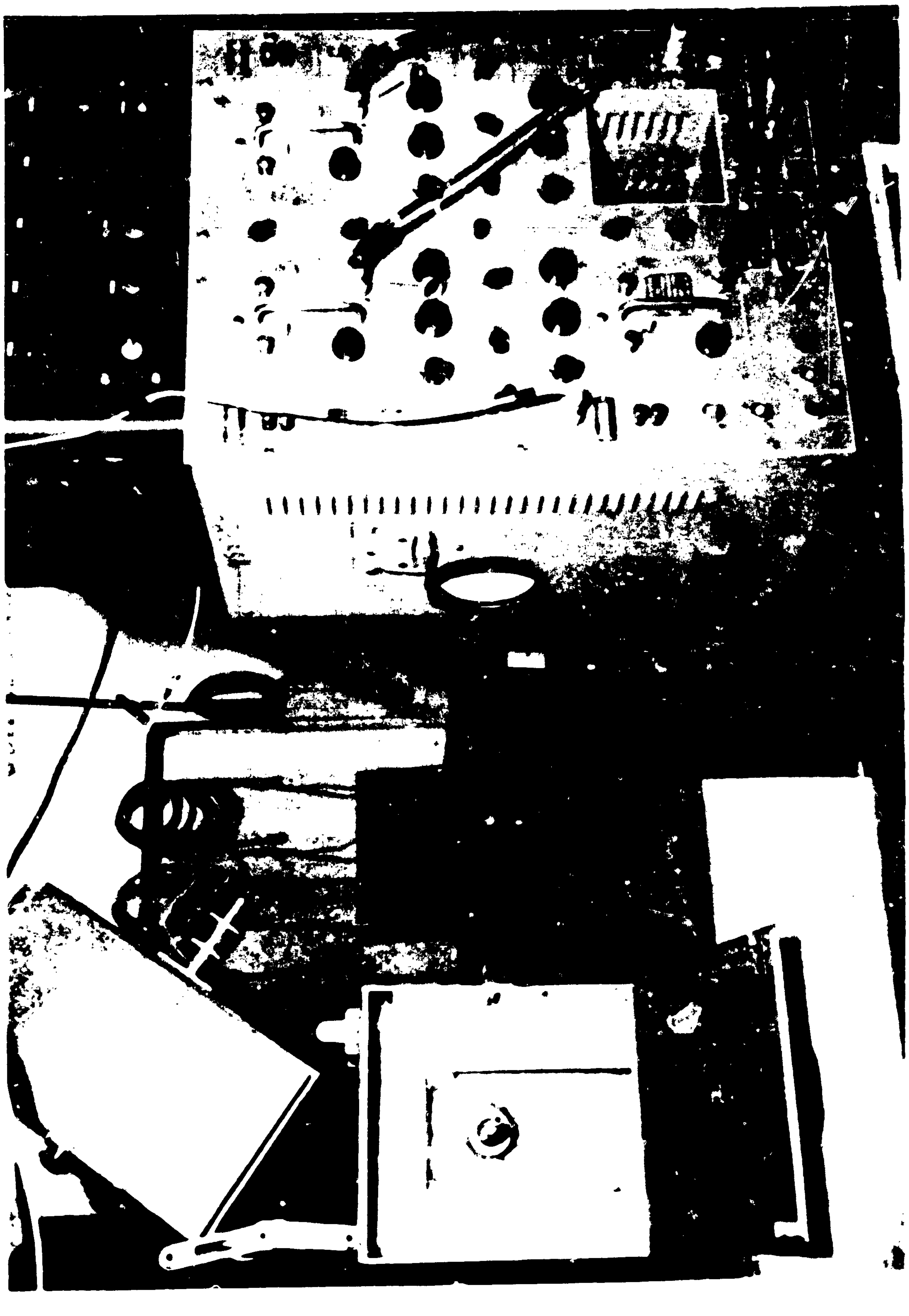

Fig 18 Drum Camera and Oscilloscope

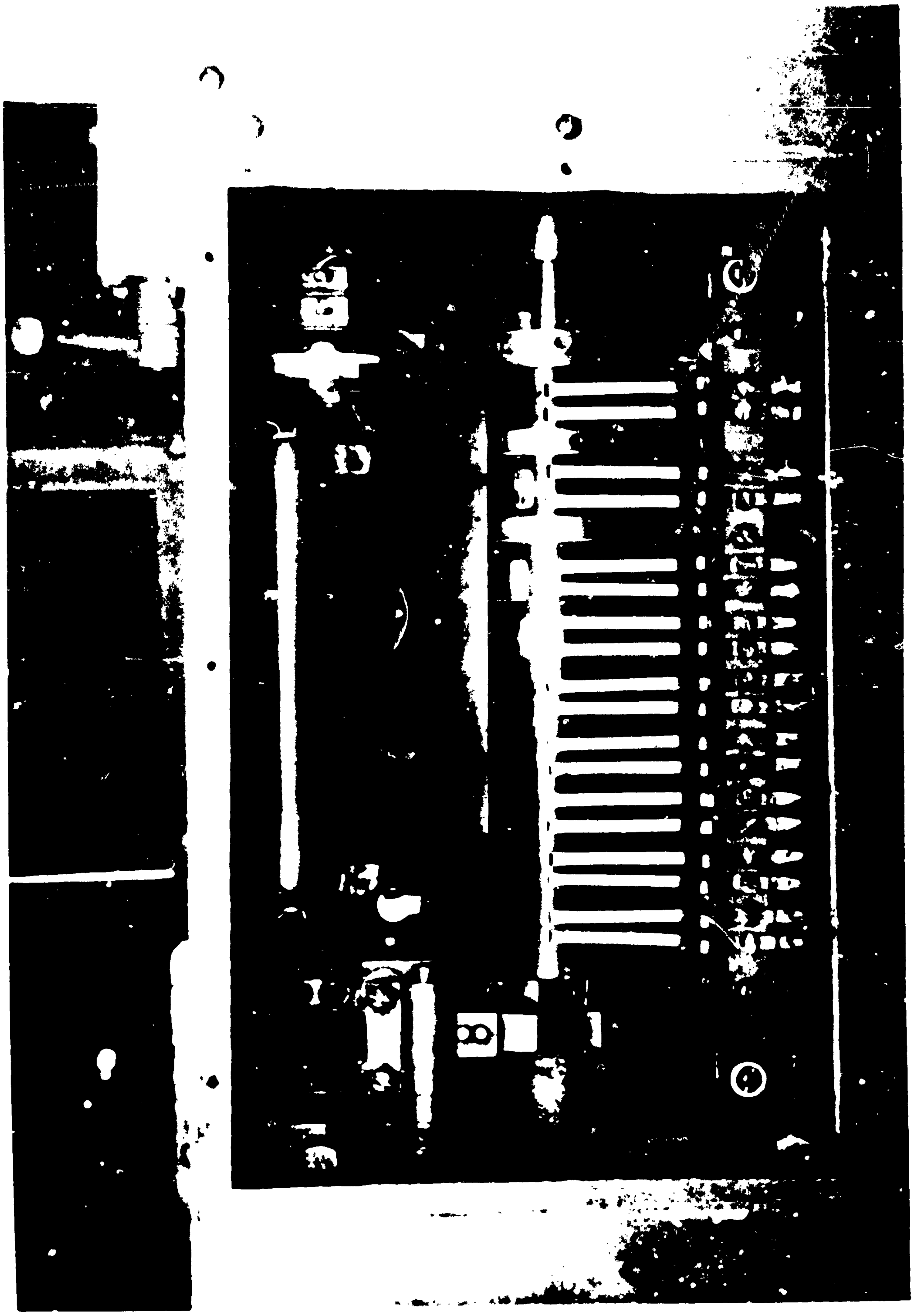

Fig 19 Sequencing Roller and Commutating Contacts

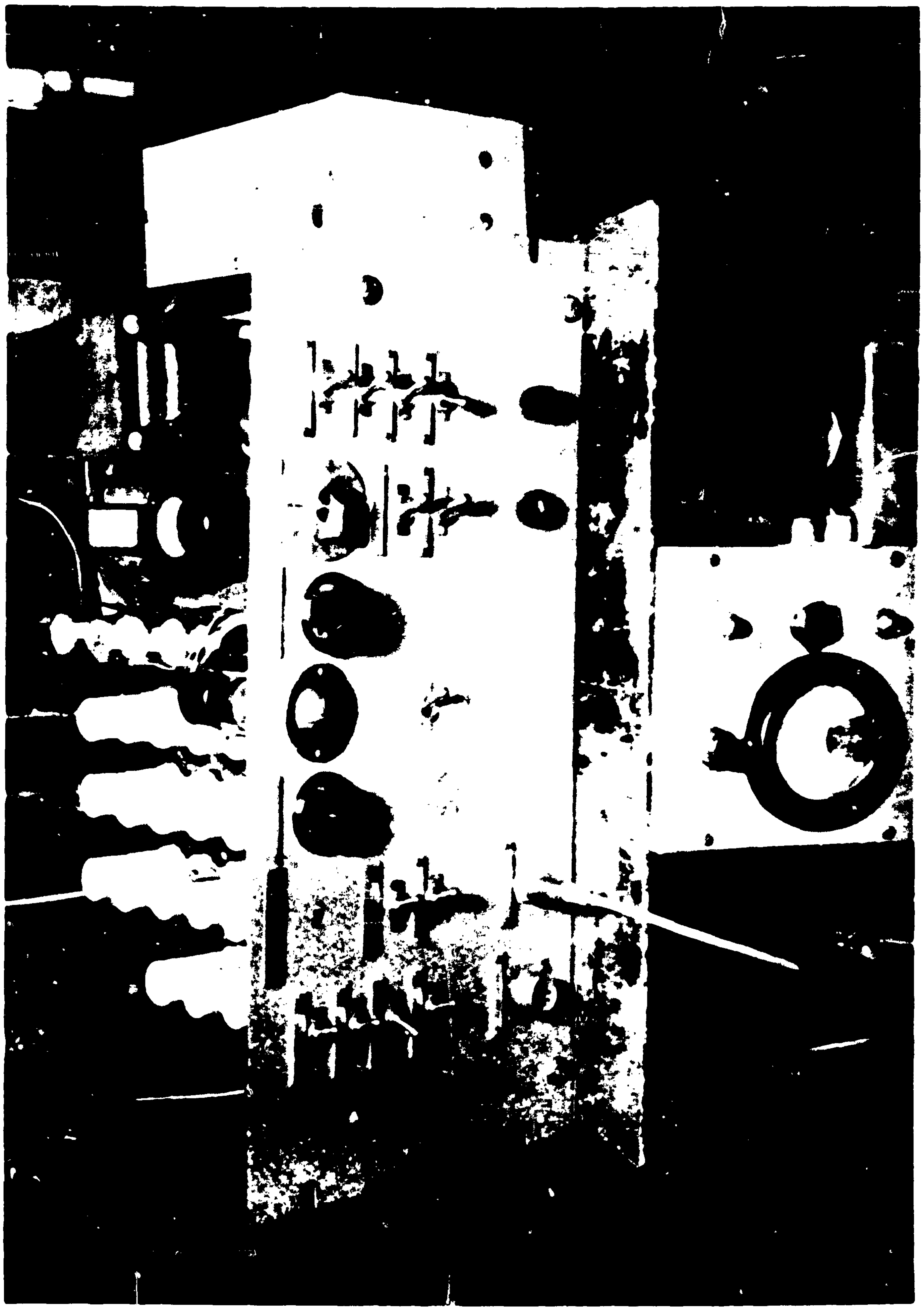

Fig 20 Sequencing Chassis and Western Electric Type 275 Relays

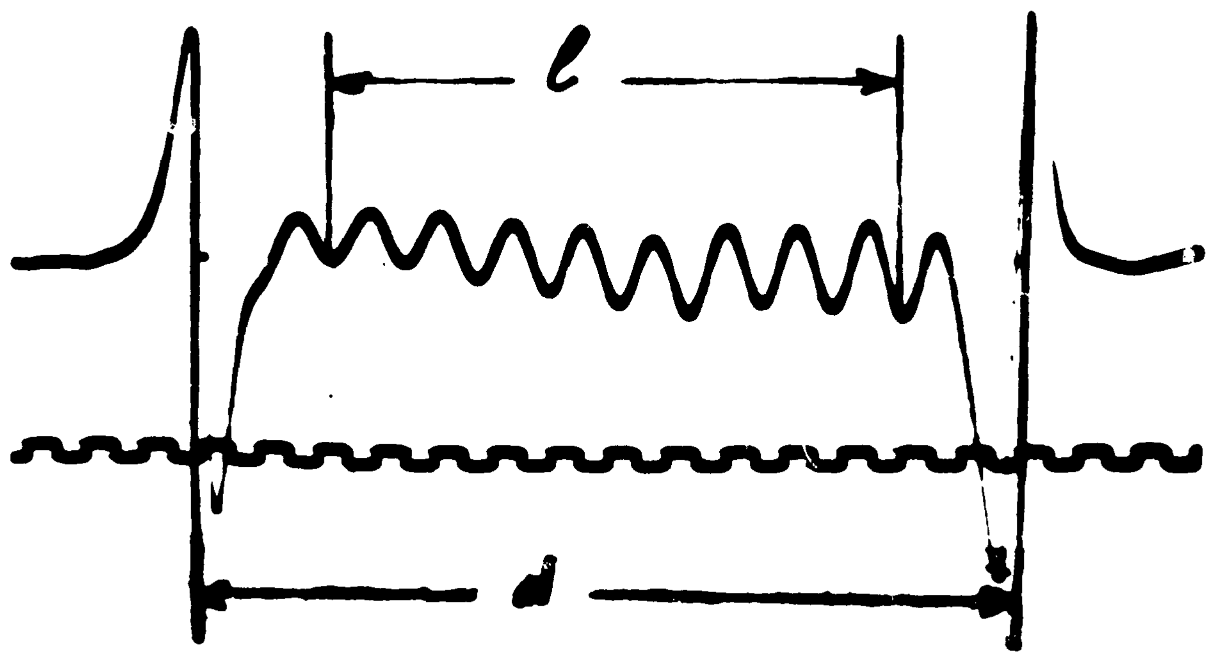

Fig 21 Typical Oscilloscope Trace

d = Distance in feet between marker coils on record

D = Actual distance in feet between marker coils

N = Number of turns chosen for measurement

l = Length in feet on N turns on record

$$\text{Spin (ft/rev)} = \frac{D \times l}{d \times N}$$

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